TM 5-331A

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

UTILIZATION OF ENGINEER CONSTRUCTION EQUIPMENT

VOLUME A—EARTHMOVING, COMPACTION, GRADING, AND DITCHING EQUIPMENT

HEADQUARTERS, DEPARTMENT OF THE ARMY

AUGUST 1967

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TECHNICAL MANUAL
No. 5-331A

HEADQUARTERS
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WASHINGTON, D.C., *18 August 1967*

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This manual supersedes chapters 2, 4, 5, 6, and paragraphs 34*c*(3) and 143 of TM 5-331, 30 November 1962.

CHAPTER 1

EARTHMOVING EQUIPMENT

Section I. INTRODUCTION

1–1. Purpose and Scope

a. This manual furnishes information and guidance to personnel responsible for utilizing and supervising the operation of engineer construction equipment. It describes the characteristics, capabilities, and application of equipment for typical construction tasks, guides for estimating the output of various items of equipment, safety practices, and expedient equipment for specific construction tasks.

b. The information contained herein is applicable without modification to both nuclear and nonnuclear warfare.

1–2. Application

a. This manual should be used in conjunction with TM 5–333, Construction Management, and the appropriate TM for the particular construction task being accomplished. Detailed information for any particular model of equipment mentioned in this manual may be obtained in the appropriate—10-series TM for that model.

b. This manual is composed of five volumes dealing with engineer equipment groupings as follows:

(1) Volume A—Earthmoving, Compaction, Grading, and Ditching Equipment.

(2) Volume B—Lifting, Loading, and Haul Equipment.

(3) Volume C—Rock Crushers, Air Compressors, and Pneumatic Tools.

(4) Volume D—Asphalt and Concrete Equipment.

(5) Volume E—Engineer Special Purpose and Expedient Equipment.

1–3. Recommended Changes

Users of this manual are encouraged to submit recommended changes or comments to improve it. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded directly to the Commandant, U.S. Army Engineer School, Fort Belvoir, Va., 22060.

Section II. GENERAL CONSIDERATIONS

1–4. Basic Production Terms and Formulas

a. Management Phases. To insure that a construction project is completed successfully by the deadline date set forth in the project directive, basic phases of management must be followed. These management phases are planning, scheduling, and supervision. The proper utilization of construction equipment is a vital part of each of these phases.

(1) *Planning.* Selection of the most appropriate piece of equipment for any given task within the project influences the overall efficiency of the project. Production records kept on previous jobs generally are a good basis for estimating each successive job.

(2) *Scheduling.* Scheduling relies on previous records of production rates updated by factors to account for weather, status of troop training, condition of equipment, and other factors peculiar to the present project, to ar-

rive at key dates for delivery of materials, completion of individual tasks, and final completion date of the mission.

(3) *Supervision.* By analyzing periodic production and progress reports and equipment availability lists, the project officer can effectively alter his original plans to keep the project as close as possible to the schedule. Supervision is concerned with maintaining a watchful eye over the entire project, including work progressing and work accomplished, and keeping in mind work that needs to be done. The mission must be accomplished on or before the deadline date.

b. General Production Formula. From *a* above, it is apparent that production estimating, production control, and production records are the basis for management decisions. Therefore, it is helpful to have a common method of reporting, directing, and recording production progress. The general expression used is—

$$\text{Rate of production} = \frac{\text{work done}}{\text{unit of time}}$$

(1) *Work done.* The term "work done" denotes in a general way the unit of progress accomplished. For example, it can stand for volume or weight of material moved, number of pieces of material cut, distance traveled, linear feet of progress for various individual tasks, or any similar production or progress one wishes to measure.

(2) *Unit of time.* The "unit of time" denotes an arbitrary time unit such as a minute, hour, 10-hour shift, day, or any other convenient period during which the amount of "work done" is accomplished.

(3) *Production.* The entire expression is the time rate of production. Examples might be cubic yards per hour, tons per shift (time lengths of shift must be recorded in any report), square feet of sheathing per day, or feet of ditch per hour.

c. General Time Formula. The inverse of the production formula is sometimes very useful when scheduling a project because it is in terms of the time required to accomplish an arbitrary amount of "work done." This formula is simply—

$$\text{Time required} = \frac{\text{time period}}{\text{unit of work done}}$$

Examples might be hours per 1,000 cubic yards, days per acre, or minutes per foot of ditch.

d. Units of Work and Time. The specific task will determine the most convenient and useful units of time and work done to use in relation to a particular piece of equipment, or a particular job. The equipment chapters of this manual deal with the most commonly used units. It is important to standardize the use of these terms on any given job so that accurate and meaningful progress comparisons and conclusions can be obtained from production data.

1-5. Materials

a. Introduction. The earth resists being moved, and the materials which make up the earth undergo a process of change as they are being moved. These changes are the result of the properties of the material. The prime question which concerns the earthmover is not about the nature of the material, but rather its physical properties. He wants to know, "How easy is it to dig, and to load?".

b. Loadability. The term "loadability" can only be explained as a general characteristic. If material digs and loads easily, it has a high degree of loadability. Conversely, if it is difficult to dig and load, the material is not very loadable. Certain types of clay and loam are considered very loadable. They can be dozed, or loaded into a scraper from their natural state. Other types of material, such as rock or hardpan, must be loosened with a ripper or even blasted before they can be moved. The choice of the type of earthmoving equipment to be used on a job depends to a great degree on the loadability of the material. For earthmoving operations, this material is placed in three categories: rock material, soil material, and rock-soil mixtures.

c. Rock. Rock material is hard and firm like ledge rock, masonry and concrete structures, large boulders, and similar material that may require drilling and blasting to remove. All other material is classified as a type of soil material.

d. Soil. Soil material is further classified by particle size and type. For instance, gravel has

large, coarse, rocky type particles while clay has small, fine, flaky type particles. Sand and silt are soils that have particle sizes in between these two extremes.

e. Rock-Soil. Rock-soil mixtures are the most common materials encountered. This material is found throughout the world and is a combination of various rock and soil materials. The name given to a mixture identifies its composition. For example, glacial drift consists of all sizes ranging from rock flour to huge boulders.

1–6. Moisture

All material in the natural state usually has some percentage of moisture in it, depending on weather conditions, drainage, and the retention quality of the material itself. Moisture retention properties are quite important to the earthmover, since moisture in soil affects its weight and handling properties. The moisture retention quality of material can be changed sometimes, but the procedure must be closely studied from an earthmoving standpoint.

1–7. Weight

The weight of material is something every supervisor is interested in knowing. He cannot accurately estimate the adequacy of his equipment to do the job unless he knows the weight of each cubic yard of material being transported. Assume the volume capacity of a scraper is 25 cubic yards and the recommended weight limitation is 50,000 pounds for a load. If the load is cinders, a relatively light material, the volume capacity will be exceeded before the weight capacity of the scraper is reached. Conversely, gravel, which may exceed 3,000 pounds per cubic yard, would exceed the weight capacity before the volume capacity is attained. In addition to the problem of load limits, weight of material also affects the way in which a scraper will load, a bulldozer will push, or a motor grader will cast material. As long as material is on the move, its weight affects the performance of the equipment moving it. For weights of specific materials see table 1–1.

1–8. Swell

When earth is removed from its natural resting place, it swells or volume expands due to voids being created during the loading process (fig. 1–1). Swell of materials can be predetermined if the general classification of the material has been established. Swell is expressed as a percentage increase in volume. For example, the swell of dry clay is 40 percent, which means that a cubic yard of clay in the bank condition, or undisturbed state, will fill a space of 1.40 cubic yards in a loosened state. By a quick reference to a table of properties of materials, a supervisor can decide the percentage of increase in size that excavating a yard of material will produce. He will know, for example, that to excavate 100 cubic yards of clay from a through-

Table 1–1. Approximate Material Characteristics

Material	*Loose* lb/cu yd	% Swell	Load Factor	*Bank* lb/cu yd
Cinders	800–1200	40–55	.65–.72	1100–1860
Clay, dry	1700–2000	40	.72	2360–2780
Wet	2400–3000	40	.72	3360–4200
Earth (loam or silt), dry	1900–2200	15–35	.74–.87	2180–2980
Wet	2800–3200	25	.80	3500–4000
Gravel, dry	2700–3000	10–15	.87–.91	2980–3450
Wet	2800–3100	10–15	.87–.91	3080–3560
Sand, dry	2600–2900	10–15	.87–.91	2860–3340
Wet	2800–3100	10–15	.87–.91	3080–3560
Shale (soft rock)	2400–2700	65	.60	4000–4500
Trap rock	2700–3500	50	.66	4100–5300

Note. Above figures are averages for common materials and exact weight and load factor will vary with such factors as grain size, moisture content, degree of compaction, etc. If an exact figure for a specific material must be determined, then a test must be run on a sample of that particular material.

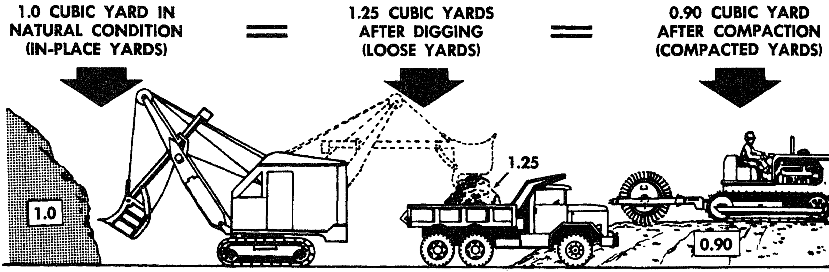


Figure 1–1. Volume change in loam caused by handling.

hill cut he will have to haul approximately 140 cubic yards, because the material will swell approximately 40 percent during excavation. Since all material that is moved is in a loosened state, it is obvious that more loose yards than actual bank yards must be moved.

1–9. Compactability

In earthmoving work, it is common to compact material tighter than it occurred in a natural state to prevent future settlement, provide a firmer road base, or for other purposes. Therefore, a typical earthmoving material cycle might be—

1 cu yd (bank) = 1.3 cu yd (loose) = .75 cu yd (compacted)

2,000 lb = 2,000 lb = 2,000 lb

Note that the basic unit of comparison is the bank yard. In an earthmoving operation, the main concern is the material in its loose state. Average conversion factors for earth volume change are given in table 1–2.

1–10. Load Factor

The apparently inert materials that normally are not thought of too seriously by the layman become a major problem when they are moved from one location to another. In the earthmoving operation the properties (loadability, swell, weight, and compaction) of materials must be thoroughly analyzed and incorporated into the construction plan. A load factor (table 1–1) is used to determine the volume of loose yard measure to bank yard measure. Similar factors are used when the material is converted to a compacted state; but in this case, the factor depends upon the degree of compaction. Loose yards times load factor equals bank yards. The load factor is derived as follows:

If 1.00 cu yd clay = 1.40 cu yd clay
(natural state) (loose state)

$$\text{Then } 1.00 \text{ cu yd clay (loose state)} = \frac{1.00}{1.40} \text{ or } 0.72 \text{ cu yd clay (natural state)}$$

Therefore, the load factor in this case for dry clay is 0.72, which means simply that if a scraper is carrying a load of dry clay of 25 cubic yards, it is carrying approximately (25×0.72) or 18.0 bank cubic yards.

1–11. Zones of Operation

The relationship of specific zones of operation to various types of earthmoving equipment is a controversial subject, with many engineers taking the stand that zonal operation has no significance when selecting equipment for projects. Civilian construction firms, however, continue to be guided by areas or zones when selecting equipment for phases of earthmoving projects. In addition, manufacturers who work closely with the Army design and manufacture equipment to meet specific requirements of areas of operation. Since the personnel manufacturing and utilizing this equipment are influenced by areas or zones of operation, the importance of zonal operation should not be overlooked. Zones of operation (fig. 1–2) to be considered when utilizing earthmoving equipment on a construction project are the *power zone,* the *slow speed hauling zone,* and the *high speed hauling zone.*

Table 1–2. Soil Conversion Factors

(Conversion factors for earth-volume change)

Soil type	Soil condition initially	Converted to		
		Bank (in place)	Loose	Compacted
Sand	Bank (in place)		1.11	0.95
	Loose	.90		.86
	Compacted	1.05	1.17	
Loam	Bank (in place)		1.25	0.90
	Loose	.80		.72
	Compacted	1.11	1.39	
Clay	Bank (in place)		1.43	0.90
	Loose	.70		.63
	Compacted	1.11	1.59	
Rock (blasted)	Bank (in place)		1.50	1.30
	Loose	.67		.87
	Compacted	.77	1.15	
Coral comparable to limestone	Bank (in place)		1.50	1.30
	Loose	.67		.87
	Compacted	.77	1.15	

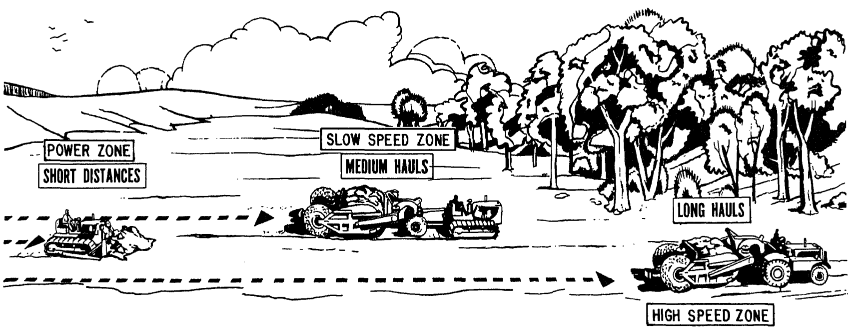


Figure 1–2. Zones of operation.

a. Power Zone. In the power zone maximum power is required to overcome adverse site or job conditions. They may entail rough terrain, steep slopes, pioneer operations, or extremely heavy loads. The very nature of the work in this area will require tractors capable of developing high drawbar pulls at slow speeds. Under the site conditions of this area, the greater tractive effort developed by the crawler tractor permits full utilization of its potential. This type of

hauling zone is similar to the power zone in that power, more than speed, is the essential factor. In this area, site conditions are slightly improved. This permits the crawler tractor to utilize excess available power, gained from improved conditions, to tow large capacity earth-hauling scrapers. Another feature of this area is that haul distances are too short for most rubber tired tractor units to build up sufficient momentum to shift into higher speed ranges. This limits their speed to that of crawler tractors and, as a result, either rubber tired or crawler type tractor-scraper combinations can achieve the same relative production. Considerations that determine a slow speed hauling zone are—

(1) Materials must be moved distances beyond economical bulldozing operations, but ground conditions do not permit rapid travel.

(2) Haul distance is not long enough to permit rubber tired equipment to travel in high speeds.

c. High Speed Hauling Zone. In the high speed hauling zone, construction has progressed to where ground conditions are excellent or long, well maintained haul roads have been established. At this point the full potential found in the high speed rubber tired tractor is utilized. In earthmoving construction this state should be achieved as soon as practicable. Once the rubber tired tractor and scraper combination can be used at its maximum speed, increased production normally results. Considerations that determine a high speed hauling zone are—

(1) Haul distances should be long enough to permit high average speeds of travel.

(2) Fair hauling conditions, both as to grade and haul road surface, should be present.

(3) Pusher tractors to assist in loading should be available.

Section III. CRAWLER TRACTORS AND DOZERS

1–12. General Characteristics

Crawler tractors are perhaps the most basic and versatile items of equipment in the construction industry. The three major assemblies of a crawler tractor are a center section and two side sections. The center section contains the power source and the operator's controls. The two side sections consist of track frames which mount tracks extending approximately the full length of the tractor. Crawler tractors are classified according to weight and minimum and maximum drawbar pounds pull. This means light, medium, and heavy class tractors; for example, D6S (fig. 1–3) the light class, D7E and HD16M (fig. 1–4) the medium class, and D8 and TD24 (fig. 1–5) the heavy class. Crawler tractors serve many purposes, such as prime movers for pulling or pushing loads, power units for winches and hoists, and moving mounts for dozer blades, side booms, and scoop loaders. This type tractor is used primarily where it is advantageous to sacrifice high travel speed to obtain high drawbar pounds pull and traction. Crawler tractors are equipped with diesel engines with ratings from 85 to 202 brake horsepower, and either 4 or 6 cylinders depending on make and model. The crawler tractor attains much of its all-type-terrain versatility from its low ground bearing pressure at the track, which varies from about 6 to 9 pounds per square inch, depending on the particular model. Crawler tractors have a distinct "flotation" advantage over wheeled tractors, which have a bearing pressure of about 25 to 35 pounds per square inch. Crawler tractors can operate in muck or water as deep as the height of the tracks. Operation in deeper water is possible, for short periods of time, if the tractor is properly waterproofed. For long moves, crawler tractors should be transported on heavy trailers. They may be moved under their own power at slow rates of speed but this shortens their operational life. Characteristics of crawler tractors are given in table 1–3.

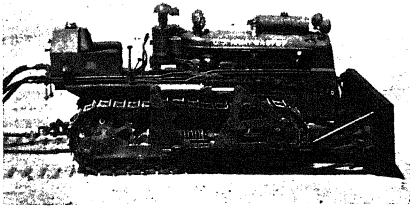


Figure 1–3. D6S crawler tractor.

1–13. Power Control Units

a. Introduction. The primary purpose of the tractor engine is to propel the tractor, but it also serves as a power source for the many and varied attachments towed by, and mounted on, the tractor. This secondary purpose is served through subsidiary power control units which may be either mechanical or hydraulic.

b. Mechanical Power Control Units. Mechanical power control units may be front or rear mounted units. The front unit is a single drum assembly mounted on the radiator guard and driven from the engine crankshaft. It is used for controlling blades only. The rear unit normally is a dual drum assembly mounted on the rear of the transmission case. A dual drum assembly is mandatory when towing a cable operated scraper. Each drum has a separate control lever. When used to operate a towed scraper, the right drum controls the raising and lowering of the scraper bowl. The left drum controls the

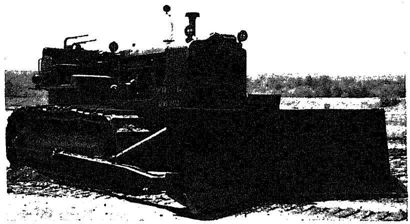


Figure 1–5. D8–9A crawler tractor with U-type dozer blade.

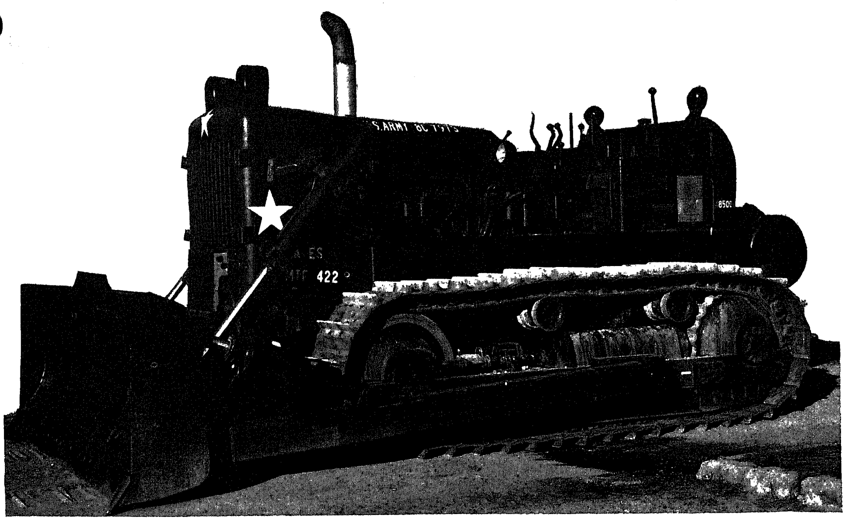


Figure 1–4. HD16M crawler tractor.

Make	Model	Speed (mph) and (drawbar pounds pull)[1] forward gears					
Crawler type		1st	2d	3d	4th	5th	6th
Caterpillar	D6S.	2.00 (12,000)	3.00 (8,000)	4.60 (5,200)	7.00 (3,400)	x	x
Caterpillar	D6B.	0.5 (17,800)	1.4 (17,500)	....	....	....	....
Allis-Chalmers	HD6M.	1.50 (12,640)	2.40 (7,930)	3.30 (5,550)	5.50 (2,975)	x	x
Caterpillar	D7 [2]	1.40 (21,700)	2.20 (13,500)	3.20 (9,020)	4.60 (6,000)	6.00 (4,270)	x
	D7E [2]	2.3	4.0	6.2	....	....	....
Int Harvester	TD20.	1.60 (28,100)	2.10 (21,200)	2.50 (17,200)	3.40 (12,300)	4.70 (8,300)	7.30 (4,600)
Caterpillar	D8–9A.	1.50 (39,150)	1.90 (30,900)	2.80 (21,000)	3.80 (14,120)	5.20 (9,490)	x
Allis-Chalmers	HD16M.	3.50 (37,204)	7.50 (26,000)	x	x	x	x
Int Harvester	TD24.	1.7–2.1 (41,130)	2.6–3.3 (26,800)	4.4–5.6 (15,800)	6.4–8.2 (10,900)	x	x
Wheel type							
MRS	*100B.	4.20 (12,000)	7.80	13.60	17.00	33.10	x
Clark	*290M.	5.10 (37,800)	10.20 (23,500)	18.20	31.90	x	x
Caterpillar	*830M	5.70 (39,125)	12.80 (23,500)	30.10 (10,000)	x	x	x

[1] Drawbar pull and rimpull figures are for elevations up to 3,000 feet above sea level. Reduce figures shown by 3 percent
[2] These tractors equipped with torque converter type transmission. Power vs speed data is given in figures 1–41 (D7E), 1–42
* Highest reverse gear; not necessarily 4th gear.

apron and ejector. When operating a rooter, only the left drum is used. The right drum can also be used to control the dozer blade if required.

c. Hydraulic Power Control Units. Hydraulically operated power control units consist of three main components—a hydraulic pump mounted on the front of the engine or on the rear power takeoff; hydraulic lines leading into a control box valve near the operator; and hydraulic rams attached to the blade or other attachment (either mounted or towed) that is to

Speed (mph) reverse gears				Horsepower (Nebr. test data)		Overall dimensions (in.)			Weight (lb)
1st	2d	3rd	4th	Drawbar	belt	Length	Width	Ht.	
2.70	x	x	4.2	x	85.00	179	98	77	15,975
2.30	3.50	4.80	6.70	....	....	187	96	102	21,460
2.00	x	x	4.1	x	108.00	148	96	70	16,000
1.60	2.60	3.80	*5.40	80.44	92.84	167	x	81	25,925
....	x	x	x	x	165.00	230	133	96	48,220
1.90	x	x	8.90	x	140.00	214	152	95	40,660
2.00	x	x	3.80	x	191	246	146	92	53,175
3.00	x	x	6.50	x	200	231	135	90	48,600
1.60	x	x	8.00	x	202	246	138	102	54,180
2.10	x	x	x	x	140.00	197	99	112	15,865
10.20	x	x	x	x	400.00	286	120	142	54,000
5.70	x	x	x	x	335.00	293	136	136	52,200

for each 1,000 feet of elevation, or major fraction thereof, in excess of 3,000 feet above sea level.
(HD16M), 1–43 (290M), and 1–44 (830M).

be operated.

1–14. Dozers

a. Introduction. The dozer usually is the first piece of equipment to arrive on a construction project and the last to leave. It is practical for many jobs at the construction site if properly used. Basically, dozer blades consist of a moldboard, cutting edges, side bits, and blade arms connecting the blade to the tractor. Blades vary in size and are designed to perform different earthmoving functions. The side bits and cut-

ting edges are replaceable and made of hardened steel. The purpose of this feature is to have these items absorb the wear and so enable continued use of the same moldboard for the life of the machine. Table 1–4 lists tabulated data on dozer blades. Dozer blade designs allow either edge to be raised or lowered from the horizontal position. The top of the blade can be pitched forward or backward, and the blade can be angled from the direction of travel. These features are not applicable to all blades, but any two of these features may be incorporated in a single blade type. The dozer, rubber-tired or track-type, considering both production and efficiency, has demonstrated its ability to do a wider variety of jobs than any other earthmoving tool. Tractor-bulldozers are the standard equipment used for land clearing. This unit works best when the ground is firm and without potholes, sharp ridges, or rocks. Uneven surfaces make it difficult to keep the blade in contact with the ground, and tend to bury vegetation in hollows rather than remove it.

b. Blade Types.

(1) *Straight blade.* The straight blade is mounted in a fixed position perpendicular to the line of travel of the tractor. It can be tilted laterally approximately 12 inches, and the blade top can be pitched either forward or backward within a 10° arc. Bull blades, now becoming obsolete in military channels, can be adjusted only through the pitched positions. Blades having a tilting characteristic are used for cutting ditches and breaking through crusted material. The tilting ability permits the concentration of the tractor power upon a small segment of the blade. The pitching characteristic will permit a variance in ground pressure of the blade; thus, penetration will be increased or decreased accordingly. Changing the blade pitch will provide a cutting or dragging action, whichever is desirable.

(2) *Angle blade.* The angle blade is designed so the blade can be set at angles up to approximately 25° to the direction of travel of the tractor. It also can be set at right angles to the tractor and used as a straight blade. When angled, the blade can be tilted up to approximately 12 inches but cannot be pitched. Angle blades are most effective when used to sidecast materials during a backfilling operation or in making a sidehill cut. Angle blades have been successfully used for rough grading operations and for spreading piles or windrows of material.

(3) *Special purpose clearing blade.* The special purpose clearing blade (fig. 1–6) is designed for the clearing of brush and trees only and should not be utilized for earthmoving. This blade is permanently fixed at an angle with a knife blade type protrusion or "stinger" extending from one end. A tapered cutting edge originates at the

Table 1–4. Data on Dozer Blades—Straight and Angle

Blade	Length (inches)	Height (inches)	Max lift above ground (inches)	Maximum pitch	Maximum tilt (inches)	Maximum angle	Weight (pounds)	Capacity cu yd (loose)
Straight D6.	99	37	36	10°	10		1,800	2.6
HD 6M	96	37		10°	10		1,800	2.6
D6B	115	38		10°	14		3,520	3.6
D7	124	46	42	10°	12		4,460	4.1
D7E	137	46	44	10°	12		7,715	5.0
HD16 M	133	52		10°	18		7,536	5.0
D8–2U	136	46	51	10°	12		5,370	5.0
TD–24	138	50	47	10°	12		8,410	5.0
Angle D7.	152	39	40		12	25°	5,345	3.8
TD 18	153	39	38		12	25°	5,420	3.8

stinger and extends to the opposite end of the dozer blade. This blade is designed to cut down brush and trees at, or a few inches above, ground level rather than uprooting them. In the case of larger trees, the operator should split them first with the stinger a sufficient number of times to weaken the tree so that it may be cut off and pushed over with the blade. Both the stinger and the cutting edge must be kept sharp and the operator must be well trained in order to achieve efficient operation.

1-15. Removing Brush and Trees

a. Brush and Small Trees. Brush and small trees may be removed by the tractor moving with its blade slightly below ground level. This will uproot or break off a number of small trees and bend the rest over so that a return trip in the opposite direction will remove the rest. It is best to clear the whole area in one direction if possible, rather than switch directions. Results will vary with the type of vegetation and the type of soil. Hard baked soil will cause a high percentage of broken trunks, while wet or sandy conditions favor uprooting, which is more satisfactory. The tractor normally is operated in first or second gear and with the blade can clear brush and small trees at the rate of approximately 1,000 square yards per hour.

b. Medium Trees, 4–10 Inches Diameter. To push trees of this size, the blade is raised as high as possible to gain added leverage, and the tree pushed over slowly. As the tree falls, the dozer is backed up quickly to clear the rising root mass. The blade is then lowered and the dozer travels forward, and digs the roots free with a lifting and pushing action. The felled trees are then ready to be pushed to the disposal area. Average clearing time is from 2 to 9 minutes per tree.

c. Large Trees, Over 10 Inches Diameter. For large trees the removal is slower and more difficult. A preliminary contact should be made with the tree, inspecting for dead limbs which might break off and fall on the operator. This contact should be made gently, with the bulldozer high and centered for maximum leverage. Before pushing over a large tree, the direction of the fall, which usually is the direction of lean, should be determined. If the tree can be pushed over in the manner described for medium trees, well and good. If the tree has a large root system, however, the following method may be used: a cut is made on the side opposite the tree's direction of fall to a depth sufficient to cut some of the larger roots. The roots on both adjacent sides are cut in a similar manner. An

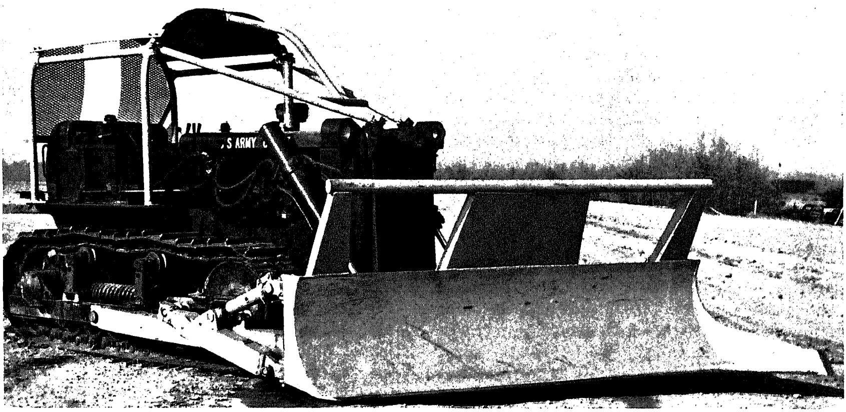


Figure 1–6. Special purpose clearing blade.

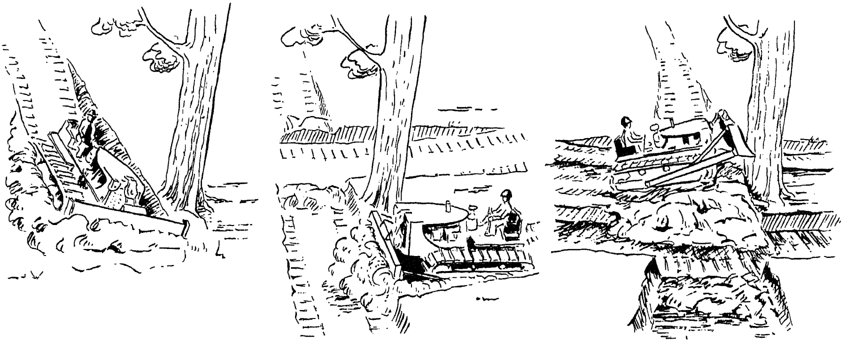


Figure 1–7. Tree removal by excavation.

earth ramp is built above the original cut so that greater pushing leverage can be obtained, and the tree is then pushed over (fig. 1–7). As it starts to fall, the tractor is reversed quickly to get away from the rising root mass. It may be necessary to cut the roots on the fourth side when large or well rooted trees are being removed. The cut around the trees should have a V-ditch shape, made with the tractor sloping downward laterally toward the tree. The stump holes should be filled so that water will not collect. Average clearing time is from 5 to 20 minutes per tree.

d. Precautions. When removing trees, precautions must be taken to avoid injury to personnel and damage to equipment. Units should never work close together, as one may push a tree over on the other. Care should be taken not to follow too closely when a tree starts to fall, as the stump may catch under the front of the tractor. The tractor will then require assistance to back off, and the bottom of the tractor may be damaged.

1–16. Rock Removal

In many construction sites, large rocks generally are imbedded in the earth with just a small portion exposed. With the bulldozer blade in the tilt position, the earth should be removed from any three sides of the rock. Now the dozer should push from the uncut side, and let the blade penetrate deep enough to get under a portion of the rock. Then as the tractor moves forward, the blade is lifted to get a lifting and rolling action. If the dozer cannot push the rock, the rock is lifted up with the blade and an assistant operator places a log or other object under the rock so the dozer can get another hold. It then continues to move forward and removes the rock by rolling. Small rocks can be removed from the construction site with a rock rake if one is available. The rock rake is designed to dig the rock free from the earth and permit the soil to pass through the rake.

1–17. Working in Hard Materials

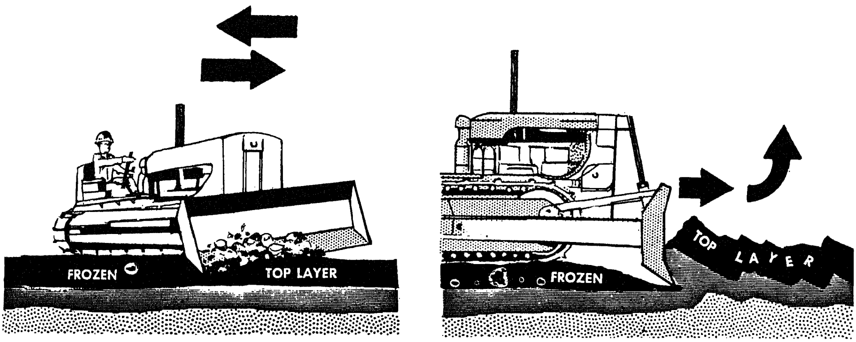
When rooters or rippers (sec VI) are not available a dozer may be used to loosen hard material. This is done by tilting the blade so that one corner of the blade is forced into the material. The blade may be tilted by driving one track lengthwise onto a ridge of material bladed up for this purpose, by placing a rock or log under the track, or by tilting the blade by adjustments provided. A thin layer of material often may be loosened by turning a crawler tractor on it. This causes the grousers to penetrate the top layer of material. Where a thin crust of frozen material is encountered, it is best to break through the crust at one point. At this point the dozer is moved onto frozen soil to get more traction. The top frozen layer is then broken up by the lifting and pushing action of the dozer (fig. 1–8). When working in rocky areas the tracks wear out faster. To help cut down on the wear, the idler roller should be placed in the top position, roller guards should be mounted, and if possible, narrower track

1–18. Working in Wet Materials

Wet material is quite difficult to move with a dozer. Where the material is too soft to hold up the weight of the dozer, each successive pass should be the full depth of the wet material. This will place the dozer on a more firm footing. The mud should be pushed far enough so it will not flow back into the cut. Provision should be made for rescue if the dozer gets stuck. Wider track shoes can be used for better flotation. The roller guards should be removed if rocks no bigger than the size of a fist are encountered.

1–19. Side Hill Excavation

One of the more important uses for dozers is in making side hill cuts. This includes the preparation of a roadway along the side of a hill. The best method for starting the cut is to start at the top of the hill, creating a bench from the top and working your way down. If the cut must be started on the side of the hill use the method illustrated in A, figure 1–9. Start by making a bench several dozer lengths long. This should be done by working up and down the slope. When working on extremely steep slopes it may be necessary to use a winch the tractor onto the bench (B, fig. 1–9) and works his way from there down the hill. If possible, start the bench on the uphill extreme of the cut and then widen and deepen the cut until the desired profile is achieved. Be sure that the bench is started far enough up the slope to allow room for the inner slope as well as the roadway itself. After a bench is constructed all the way along the hill either dozers or scrapers can be used to complete the cut. Care must be exercised to insure that the proper slope is maintained on the inner slope during construction. It is very difficult to change the slope once it is constructed. It is advisable to use the step method of constructing this slope. Using this method a layer of material is removed from the bottom of the cut, then the next cut, or layer, should be started a specified distance from the inside slope. The distance moved away from the slope for each successive layer along with the depth of the layer determines the slope ratio. Where it is necessary to start at the bottom of the cut, raise the blade as high as possible and hold it against the slope. Cast the material out to the outside, building a ramp for the machine to work on as it progresses up the hillside. The in-



A. TILT BLADE

B. MOVE FCRWARD AND BACKWARD UNTIL FROZEN LAYER IS WORN THROUGH

C. BRING BLADE UNDER FROZEN SURFACE AND LIFT BLADE

Figure 1–8. Bulldozing frozen ground layers.

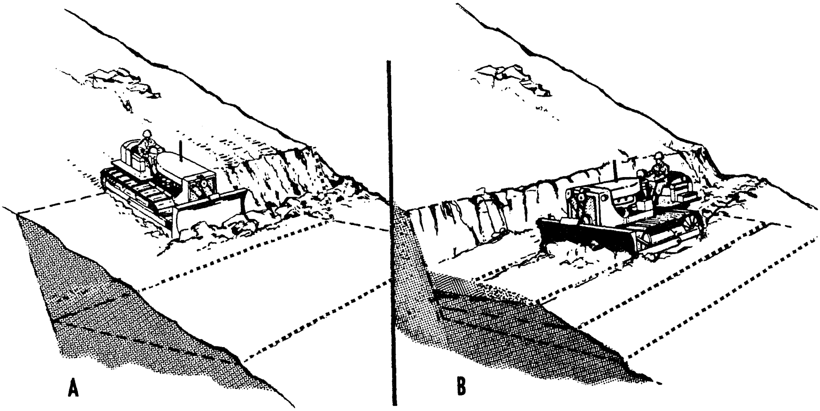


Figure 1–9. Dozer making sidehill cut.

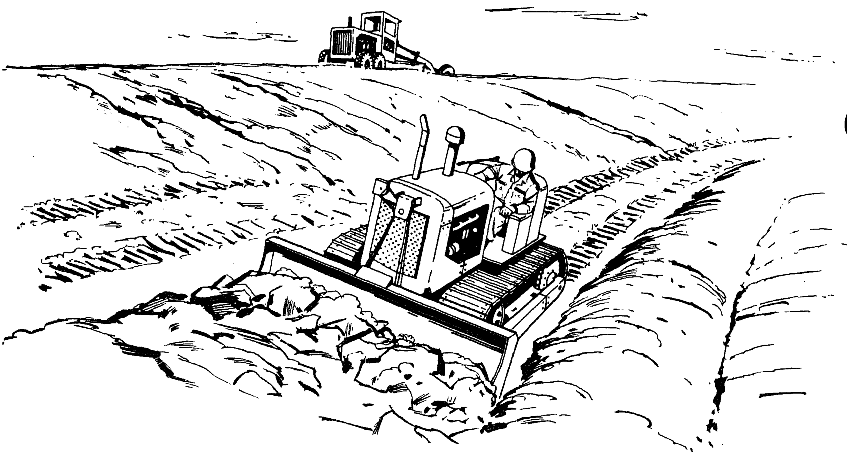


Figure 1–10. Dozer working parallel to right-of-way, finishing side slopes.

side or slope side of the roadway should be kept lower than the outside. This will allow the equipment to work on the outer edge more effectively and will decrease the erosion of the outer slope. An angle blade is preferred for making side hill cuts because of its sidecasting ability.

1–20. Finishing Side Slopes

Two commonly used methods for finishing side slopes with dozers are illustrated in figures 1–10 and 1–11. In finishing side slopes by working parallel to the right-of-way (fig. 1–10) the

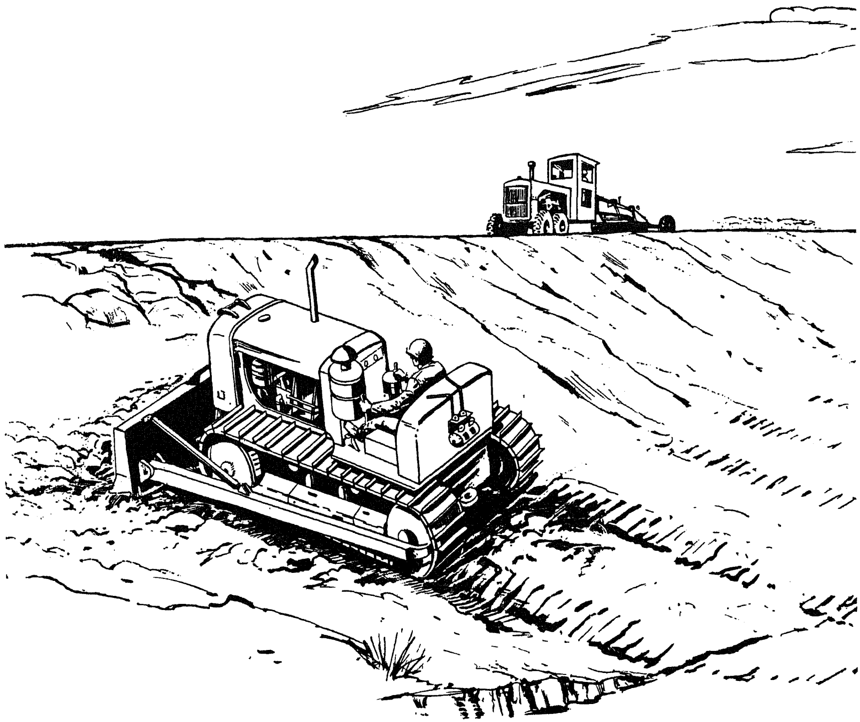


Figure 1–11. Dozer working diagonally finishing side slopes.

dozer starts at the top. Earth from each pass will fall to the lower side of the blade and form a windrow which is picked up on succeeding passes, filling irregularities in the terrain. Care should be taken not to allow the blade corner to dig since this will steepen the slope beyond job specifications. In finishing side slopes by working diagonally, the dozer starts at the bottom and works diagonally up the slope (fig. 1–11). A windrow is formed and is continually drifted to one side, tending to fill low spots or irregularities. Operator trainees should be cautioned that this latter method is one of the few instances where a dozer may be most efficiently employed cutting upgrade.

1–21. Techniques To Increase Production

The following techniques save time and increase output when conditions permit their use:

a. Blade-to-Blade Dozing. Blade-to-blade dozing (fig. 1–12) gives increased output when material is to be moved distances of 50 to 300 feet. At distances less than 50 feet, the extra yardage obtained is offset by the extra time required to maneuver the second dozer into position. More than two dozers may be used effectively in blade-to-blade dozing. Blade-to-blade dozing has disadvantages however, including the inclination of some operators to stop and talk, and the waits for minor repairs and adjustments to the adjacent machine.

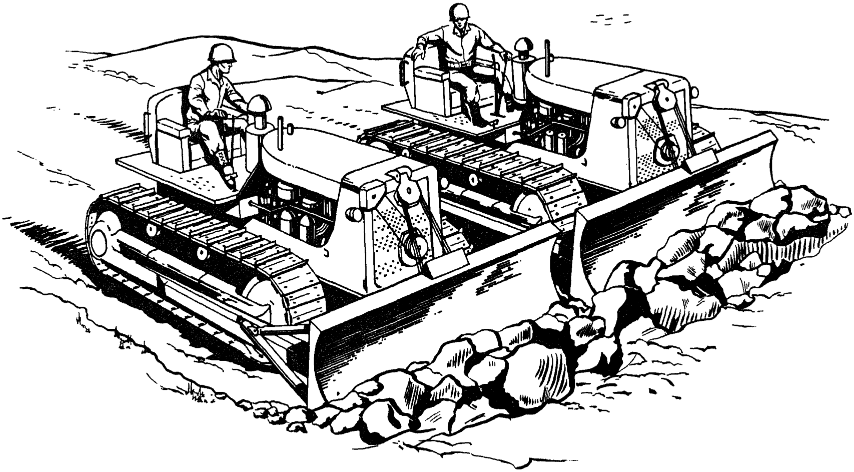


Figure 1–12. Blade-to-blade dozing.

b. Slot Dozing. Slot dozing (fig. 1–13) uses spillage from the first few dozer passes to build a windrow on each side of the dozer's path, which forms a trench, preventing spillage on subsequent passes. Cut sections, where possible, should be "slotted" alternately with narrow uncut sections between "slots". These narrow uncut sections can then be removed by normal dozing. With favorable grades and soil conditions the increase may amount to as much as 50 percent.

c. Downhill Dozing. In downhill dozing it is not necessary to travel down the hill with each load. Several loads can be piled at the brink of the hill and pushed to the bottom in one pass. Whenever feasible, dozing should be done downhill since it will increase production.

Section IV. RUBBER TIRED TRACTORS

1–22. Introduction

Rubber tired tractors are designed for greater speed and mobility than crawler tractors, while providing almost as much power. The Army has several varieties of rubber tired tractors now in use, such as the four wheel with four wheel drive as shown in figures 1–14 and 1–15. Table 1–3 lists data and power characteristics of rubber tired tractors. Experienced earthmovers have found that rubber tired tractors used in earthmoving operations can move materials more economically than either crawler tractors with scrapers or truck and shovel fleets. This is particularly true where speed is the primary consideration on long hauls. Besides towing earthhauling scrapers and trailers, the rubber tired tractor can, through the use of various mounted attachments, perform the same work as the crawler tractor in pioneer phases of construction. However, the rubber tired tractor's capability to perform this type of work is limited by its traction and comparatively high bearing pressure. The use of the wide base, low pressure, and large diameter tires has improved but not eliminated these shortcomings.

1–23. Characteristics

a. Power. The main advantage of the rubber-tired tractor is its high speed of travel while

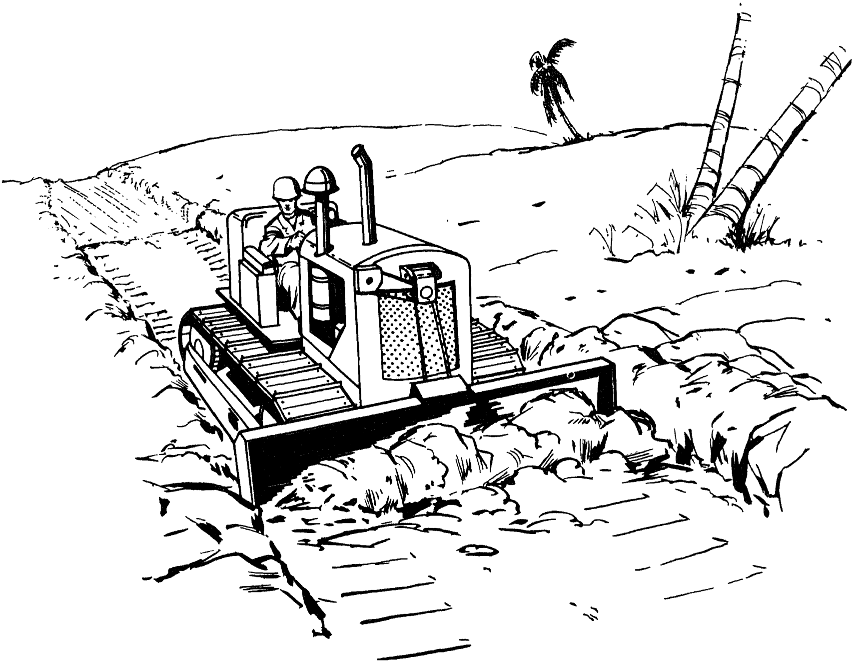


Figure 1–13. Slot dozing.

towing a payload. Rubber-tired tractors traveling at 3 miles per hour (mph) can exert a pulling force of 32,000 pounds, and can travel as high as 32 mph while exerting 3,250 pounds pull. The pulling force of rubber-tired tractors is rated in pounds rimpull. Rimpull is a term which is used to designate the tractive force between the rubber tires of the driving wheels and the surface on which they travel. Rimpull can be converted to drawbar pull by making deductions for external conditions which must be overcome in moving the tractor. The primary conditions which exist are tire flexing and wheel penetration. Since crawler tractors are always rolling on a smooth road, formed by the steel track shoes, there is no flexing or tire penetration to be considered, and the drawbar pounds pull will remain constant. However, with rubber tired tractors, tire flexing and wheel penetration do exist, and will vary considerably with underfoot conditions. Consequently, the drawbar pounds pull will also vary considerably. For this reason, it is necessary to rate rubber tired tractors in rimpull while crawler tractors are rated in drawbar pull.

b. Traction. It was mentioned earlier that one of the weakest characteristics of rubber tired tractors is the poor traction that exists between the unit and the surface over which it is traveling. When compared with the tracks of crawler tractors, the coefficient of traction for rubber tires on most haul surfaces is lower. Consequently there is a greater possibility of wheel slippage which may reduce the tractive effort. Conversely, the traction of rubber tires is better than tracks when operating on sur-

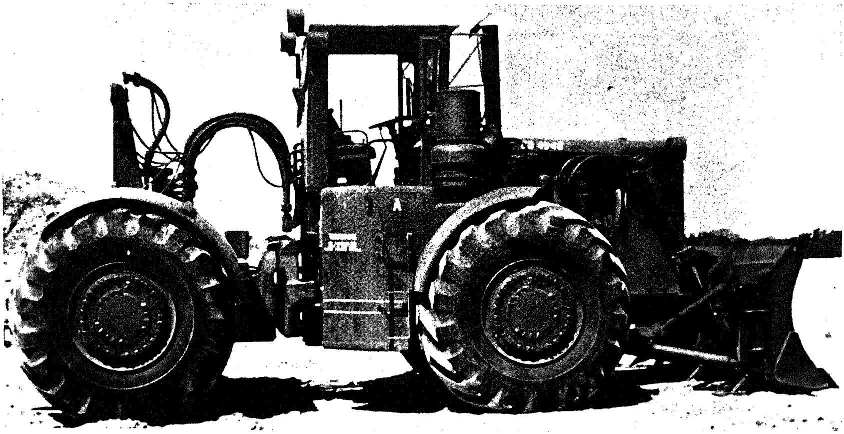


Figure 1–14. Rubber-tired tractor, four wheel drive (Caterpillar 830M).

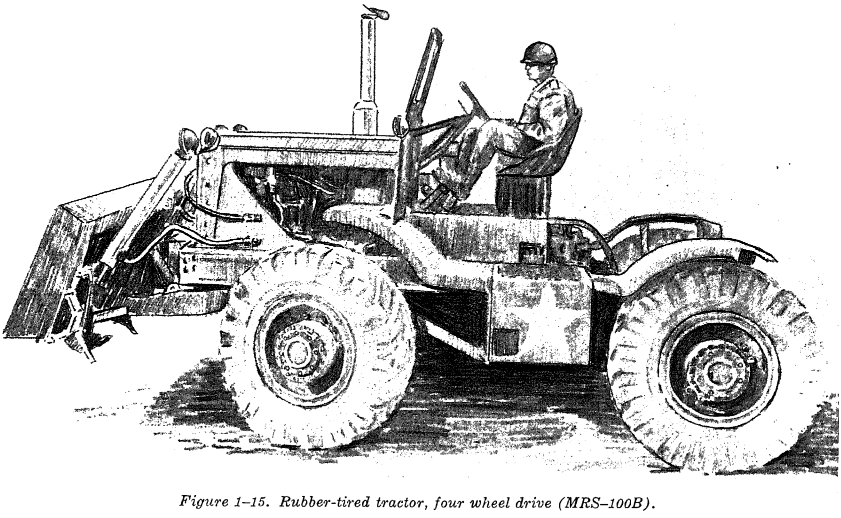


Figure 1–15. Rubber-tired tractor, four wheel drive (MRS–100B).

faced areas. The available traction of a unit is the product of two factors—the coefficient of friction that exists between the drive wheels and the surface over which it is traveling, and the weight applied to the drive wheels. Therefore it is necessary to know whether the tractor is two- or four-wheel drive, and how much weight is distributed to the drive wheels.

c. Flotation. A distadvantage of rubber-tired tractors is the high bearing pressure (up to 35 psi) at the ground contact area of the tires as compared to the bearing pressure for tractor crawler units (6 to 9 psi). This flotation characteristic sometimes restricts the efficient utilization of these items to fairly stable terrain. On the other hand, if the ground is stable and all other considerations are equal, the high speed characteristics of these tractors are preeminent.

d. Capabilities. Rubber tired tractors can mount or tow basically the same items used with crawler tractors. Salient features of rubber tired tractors are—

(1) High travel speeds.

(2) No transport equipment required.

(3) No travel damage to paved areas.

(4) Good traction on paved areas.

(5) Compaction of materials due to the high ground bearing pressures.

Section V. SCRAPERS

1–24. Introduction

Scrapers, towed by crawler or rubber tired tractors, are primarily designed for self-loading, hauling, and dumping during the earthmoving phase of construction. The scraper has three basic operating components. The bowl, which can be raised and lowered, is the load-carrying component of the body and is equipped with a cutting edge on the front bottom of the bowl. The apron is the front wall of the bowl and can be raised and lowered independent of the bowl. The tailgate, or ejector, may be the rear wall of the bowl, which is moved back to make room for the load and forward to discharge it; or it may be the rear wall and floor of the bowl, which is tilted upward and forward to dump the load. Although there are various sizes, the Army has standardized on 7.5- and 18-cubic yard capacity bowl scrapers. This equipment is standardized to match the best loading and best hauling units, and, as must be expected of any composite equipment, it is not superior to other equipment in both hauling and loading. However, the ability of the scraper to load, haul, and spread earth in one normal working cycle gives it a definite advantage on most earthmoving projects. The efficient operating range for the utilization of scrapers is 300–1,200 feet when towed by a crawler tractor and over 1,200 feet when towed by a rubber tired tractor. For earthmoving operations under 300 feet it usually is more efficient to use a dozer. The tractor-scraper can work alone if necessary, but production usually is increased when it is assisted by other equipment. Support equipment for scrapers normally includes rooters, pusher tractors, and graders.

1–25. Characteristics

a. Bowls. Scraper bowls usually are one of two major designs—the open bowl and the closed bowl. Table 1–5 lists data on scrapers.

(1) The closed bowl type has a superstructure of supporting sheaves, operating arms, and cables which complicates shovel loading the scraper from above. Although closed bowl scrapers are no longer being procured, there are many in the military system and most can be expected to last for many years to come.

(2) The open bowl type (fig. 1–16) does not have the superstructure of supporting sheaves and operating arms, and therefore can be readily loaded from above, using other equipment, as well as being self-loading.

b. Cutting Edges. The cutting edges of scrapers are made of wear-resistant steel and are bolted to the bottom of the bowl on the front edge. The three main types of cutting edges are—

(1) The straight cutting edge, which is most efficient for smooth finish grading.

(2) The curved cutting edge, which provides better penetration than the straight edge.

(3) The three piece cutting edge, with the center piece held ahead of the two side pieces for improved penetration.

c. Control Units. The traveling, steering, and digging power of the scraper is provided by the operation of the towing tractor. Individual motions of the bowl, apron, and ejector are power-

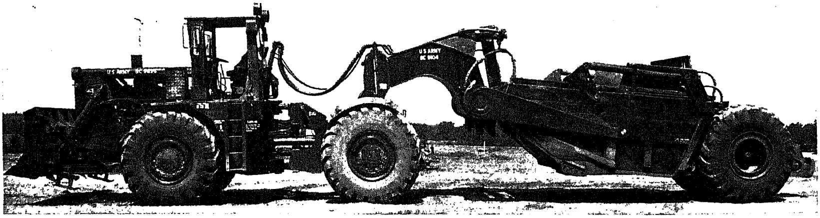


Figure 1–16. Open bowl type scraper (18 cu yd) with rubber tired tractor (Clark 290M).

Table 1–5. Characteristics of Towed Scrapers

Make and model	Weight (lb)	Capacity struck (cu yd)	Capacity heaped (cu yd)	Overall width (in.)	Cutting edge width (in.)
Murray AR 775, 2 or 4 whl.	11,700	7.5	9	100	83¼
Le Tourneau	30,500	18.9	24.1	124	105
Euclid 58 SH–6	33,500	18	23	124	105
Curtis-Wright CWT–18M 2 or 4 whl.	38,900	18.25	23.63	124	106

ed by the towing tractor's rear mounted power control unit. Although the scrapers being procured by the Army now are hydraulically operated, there are still serviceable cable operated scrapers in the system. The hydraulic system provides a positive down pressure to the bowl's cutting edge. This increases the cutting force of the smaller size scrapers in hard materials.

1–26. Production Techniques

To cover the application of scrapers and to secure maximum production, it is necessary to break the basic earth hauling cycle into specific operations. The logical breakdown is in load, haul, and spread elements.

a. Loading or Digging.

(1) Downhill loading makes use of the force of gravity on the tractor and scraper to obtain larger loads in less time. The added force of gravity is 20 pounds per gross ton of weight per 1 percent of downhill grade. The downhill pull will add more material per load, and the added material will in turn add further to the total gravitational force.

(2) Straddle loading (fig. 1–17) gains time on every third trip because the center strip loads with less resistance than a full cut. After the first scraper has made a cut, the second scraper should make a parallel cut leaving a 4- or 5-foot wide island between the two cuts. The third scraper can straddle this island of earth to obtain its material rapidly.

(3) Pusher loading (fig. 1–18) normally is used to obtain maximum production. Crawler, and occasionally rubber tired, tractors with scrapers may load without assistance, but generally it is more economical to use pusher assistance to reduce loading time. With few exceptions, pusher assistance for self-propelled, rubber tired scrapers is essential to decrease loading time and decrease tire spinning, therefore increasing tire life.

(*a*) Backtrack loading usually is used where the cut is fairly short and it is impractical to load both directions. This is an inefficient method due to

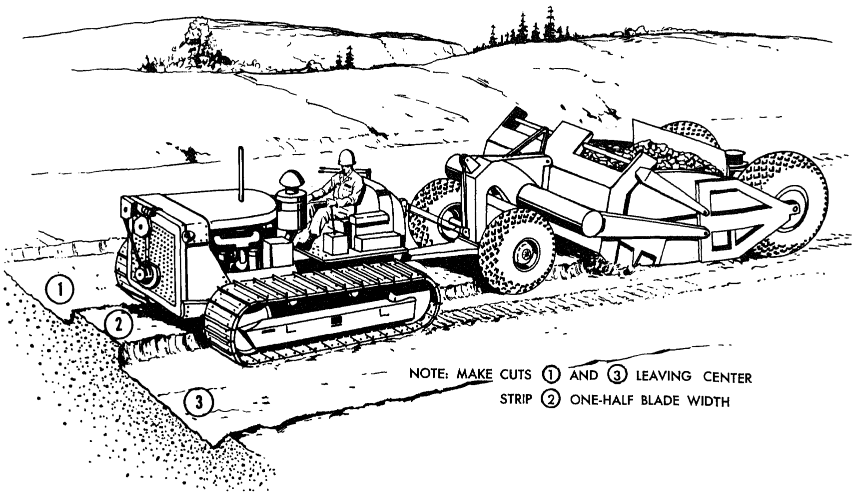


Figure 1–17. Straddle loading with scraper.

the time spent in backing up and maneuvering for the next load. If the cut is wide enough other loading methods should be used.

(*b*) Chain loading is employed where the cut is fairly long, making it possible to pick up two or more scraper loads without backtracking. The pusher loads one unit, then moves in behind another unit moving parallel to the first in an adjacent lane.

(*c*) Shuttle loading usually is used for short cuts where it is possible to load in both directions. The pusher pushes one unit in one direction, then turns and push loads a second unit in the opposite direction.

(4) Optimum loading time is of major importance when considering maximum output. Pusher loading scrapers generally should be loaded within 1 minute and within a distance of 100 feet. Additional time and distance may be used to obtain extra yardage if the haul is long enough and the added yardage is great enough to offset hauling fewer loads because of longer loading time.

(5) Personnel and equipment controlling and operating in the borrow pit area should be the best in the organization. Inefficient operation in this area will result in progressive inefficiency throughout the earthmoving operation phase of construction. The loading unit should not depend on the pusher to do all the work. Conversely, the wheels or tracks should not be spun in an effort to pull away from the pusher. Traffic control within the borrow pit area will reduce wait time and excess travel of earthmoving support units.

(6) The operator should enter the loading area at his high return speed. If the approach and cut are relatively level and smooth this is a safe and practical practice. The cut supervisor or pusher tractor operator should indicate the loading lane. The pusher tractor should be waiting about 45° off the lane to be cut, allowing the loading unit to come in with the least delay

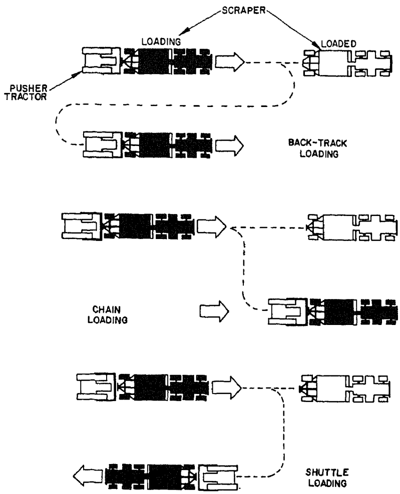


Figure 1–18. Push loading methods.

and difficulty. The scraper operator should start the loading operation before the push tractor makes contact. As the scraper speed decreases the pusher should make contact and start assisting in the loading operation. The pusher should continue pushing after a full load is gained giving the scraper a boost out of the area.

(7) The scraper should leave the cut as fast as possible, traveling a few feet before the bowl is lifted to the carrying position. This will spread the loose material that has been piled up in front of the cutting edge and result in a smooth cut, allowing the following scraper to maintain speed.

(8) Maintaining adequate drainage throughout the borrow pit operation will reduce compulsory downtime caused by bad weather. Loading cuts should be made in such a manner that uniform graded slopes are constantly present.

(9) When loading in a through-hill cut, it is important that the loading area be cut so that the centerline remains the high point. In order to maintain this desired crown, turn the tractor scraper unit, empty, from the center of the cut to the outside so the scraper will come at an angle against the side slope of the cut. Drop the scraper bowl and start digging when the tractor is parallel to the slope. This will cause the scraper to dig lower on the slope side. This allows the equipment to work the outer edge of the cut more effectively making it easier to maintain the desired bank slope and also provides drainage of the cut area.

(10) Different materials will require various loading techniques.

(*a*) Loam and most clays cut easily and rapidly with a minimum effort. The very hard clays should be loosened by rooters or scarifiers before loading.

(*b*) Sand, with little cohesion between its particles, has a tendency to run ahead of the scraper blade and apron. The finer and drier the particles, the worse this condition becomes. When loading sand, the best method is as follows: Enter the loading area fast, lowering the bowl slowly and picking up as much as possible by using the momentum of the tractor-scraper unit. This will fill the hard-to-reach rear area of the bowl. Then shift into a lower gear to match pusher tractor speed and pump the bowl up and down. For best results in pumping, drop the bowl as the scraper rear wheels roll into the depression of the previously pumped area, and raise the bowl as the wheels are climbing out of it (fig. 1–19). To top out the load, drop the bowl sharply two or three times at the end of the loading area.

(*c*) Loading rock and shale with scrapers is at best a difficult task, causing maximum wear and tear on the equipment. Rooting will ease the problem. In some soft rock and shale the scraper with pusher assistance may be able to secure the load with-

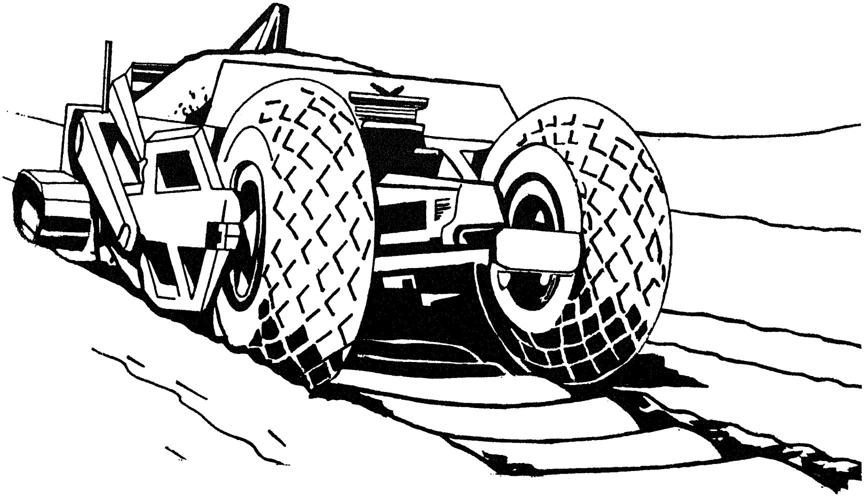


Figure 1–19. "Pumping" with scraper.

out prior preparation. When loading stratified rock start the scraper blade in dirt, where possible, moving in to catch the blade in planes of lamination and thus forcing materials into the bowl. Pick up loose rock or shale on the level or slight upgrade, with the blade following planes of lamination.

b. Travel Time (Hauling). Travel time includes haul time and return time. Here the power and characteristics of the tractor attached to the scraper become of major importance. Tractors can tow large size scrapers but at reduced speeds. Careful judgment must be exercised when teaming up tractor and scraper combinations (where possible) to insure that the end result will provide maximum production. The job should be planned to avoid adverse grades because they can drastically reduce production. Haul roads should be laid out so no unnecessary time is wasted in maneuvering. Where grades permit, it should be remembered that the shortest distance between two points is always a straight line.

(1) Avoid long slow turns. Long turns mean longer, slower cycles. Turns should be made on the shortest radius possible, and at the highest speed consistent with safety. Valuable time can be saved on short-radius turns.

(2) A figure-8 cycle should be used whenever possible. On scraper work, as much as one-half of the turning can often be eliminated by using this load pattern (fig. 1–20). If possible, load alternately at either end of the fill (fig. 1–21), or the scraper can load at a central point and spread in opposite directions. Output is increased in either case.

(3) Space rigs efficiently. Rigs should be teamed according to speed whenever possible. Put crawler-scrapers on one section of the job and self-propelled, or wheeled tractor, scrapers on another. They should use different haul roads if at all possible. No haul rig can travel faster than the unit ahead of it, and it frequently is difficult or impossible to pass. The operator should speed up to close a long gap, and slow

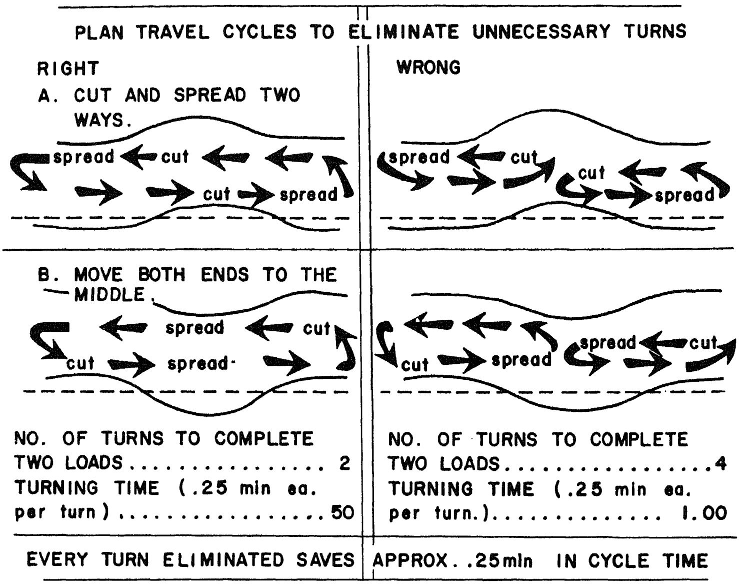


Figure 1–20. Cut and spread sequence.

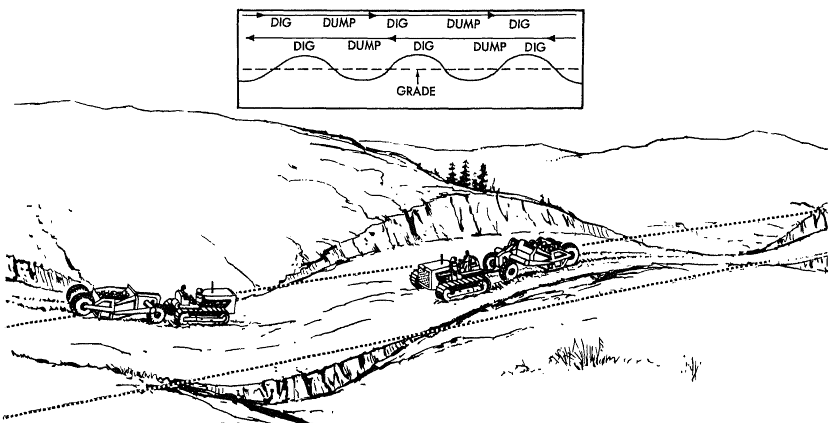


Figure 1–21. Two cuts with common fill.

down when he is too close to the rig ahead. The operator should dump at the end of the fill nearest the cut when he is lagging far behind the next scraper, and at the far end when he is too close to the next scraper.

(4) Haul roads should be kept in good condition. Eliminate ruts and rough washboard surfaces with a grader or dozer. If neither is available, the scraper operator should drop his blade occasionally on his return trip to level high spots and fill holes. A well maintained haul road permits traveling at higher speeds, increases safety, and reduces operator fatigue and equipment wear.

(5) Sprinklers should be used to reduce dust. Roads kept moist (but not wet) will pack into hard, smooth surfaces, permitting higher travel speeds. Dust tends to get into all parts of the scraper, increasing lubrication time and causing additional wear. Reducing the amount of dust helps alleviate this in addition to providing better visibility and less chance of accident.

(6) Once on the haul road, the unit should travel in the highest gear that is safe for road conditions. When possible, the scraper bowl should be carried fairly close to the ground. This lowers the center of gravity of the scraper and the chance of upsetting is less.

(7) Avoid unnecessary lugging. The operator should shift down when momentum is lost. Lugging the motor usually results in a slower speed than the top range of the next lower gear. Even though the machine can make it,

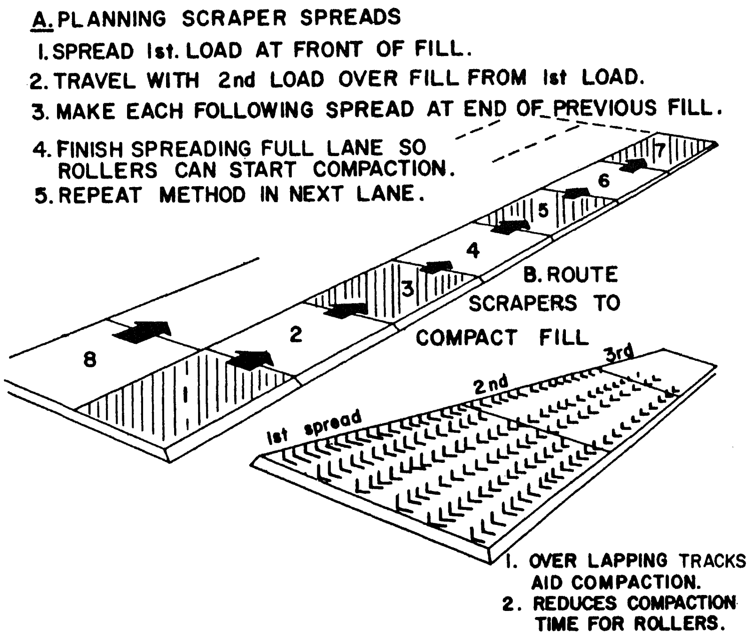


Figure 1–22. Sequence of scraper spreading.

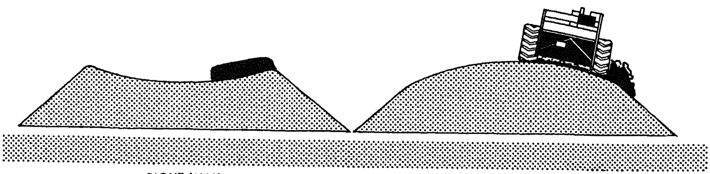


Figure 1–23. Maintaining desired fill slope.

it is better to shift down and accelerate faster.

c. *Spreading* (fig. 1–22).

(1) In planning scraper spreads—

(*a*) Spread first load at start of the fill.

(*b*) Travel with subsequent loads over the previous fill, provided lifts are small.

(*c*) Make each following spread starting at the end of the previous layer.

(*d*) Finish spreading in one full length before starting a new lane, so that rollers can begin compaction.

(*e*) Route the scrapers to compact the fill. Overlapping tracks aid the compaction of the entire area and reduce the compaction time necessary with a roller.

(2) Spread in the highest gear permitted by the haul road condition and the characteristics of the fill material. Slowly dribbling the load at low speed slows down the cycle.

(3) Time should not be wasted on the fill: As soon as the load is dumped, the rig should get back on the haul road and return to the cut as fast as possible. Plan the exit from the fill to avoid soft ground and detours around trees or other obstacles.

(4) Make the fill high on the outside edges (fig. 1–23). This prevents the scraper from sliding over the slope. Accurate slopes can thus be maintained to desired heights, eliminating the necessity of handwork. If the fill is not made in this manner, the scraper might slide over the fill, and the slope would be damaged. It would also be impossible to maintain an accurate degree of slope, because of the tendency to work away from the edge of the fill. In the event of rain, however, the low center should be built up for drainage.

(5) Different materials require different dumping procedures. Sand should be spread as thin as possible, to allow better compaction and make traveling over the fill easier. When operating in wet or sticky material, difficulty may be experienced in unloading or spreading. The following procedure should be used when operating in this type of material. Do not try to make too thin a spread when unloading. Keep the bowl high enough to allow the material to pass under the scraper. Material not having enough room to pass under the scraper will roll up inside the bowl

into a solid mass that will be difficult for the tilt floor or tailgate to eject. For best results in wet or sticky material, bring the tilt floor or tailgate forward about 12 inches at a time. After each forward movement, return the tilt floor or tailgate approximately 6 inches. This allows the material inside the bowl to settle back and loosen up. Repeat this operation until the bowl is emptied.

***Caution:* Do not try to force the load out too fast, because this also will cause the material to roll up in front, and may result in cable breakage.**

Section VI. ROOTERS AND RIPPERS

1-27. Rooters

Rooters (fig. 1-24) are invaluable on many earthmoving operations where material is too hard for normal scraper or shovel loading. They are used ahead of the loading equipment to break up the material into easily handled sizes. The rooter shanks have both a forward and a downward slant. This design tends to pull the shoes deeper when digging, thus facilitating penetration. The rooter shanks are removable, and it is permissible to use either the center or the two outside shanks. This provides a variance of breaking force on the shoes; that is, if only two shanks are used, a greater force is exerted by each shoe than if all three shanks are used. Thus, the material to be broken could be harder than the material that could be broken by using all three teeth. The same is true for harder digging with one tooth campared with two teeth.

1-28. Back Rippers

Back rippers consist of four curved shanks with lock-on teeth, pivoted from housings that are mounted at equal spacings on the back of dozer moldboards or on the C-frames of angle dozers (fig. 1-25). The size of these rippers varies with the size of the dozer blade to which they are attached. Back ripping is the operation of loosening the ground with the teeth on the dozer blade while the tractor is backing up in position for the next pass. The addition of the ripper teeth increases the productivity of the dozer by giving it this added capability of physical loosening of the material to be moved on the next dozer pass. Back rippers can be mounted on either the mechanical or hydraulic operated blades, and can penetrate to depths up to 9 inches. When the tractor moves forward and the blade is used for earthmoving, the teeth swing to the rear and drag freely on top of the ground. When traveling in reverse, the teeth are locked in the down position, thus ripping up the material. Each of the four teeth can be individually locked out of the ripping position, thereby making it possible to use any combination of teeth desired.

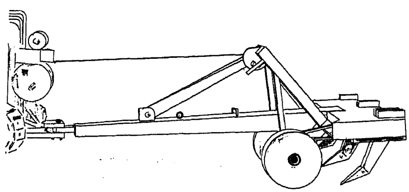


Figure 1-24. Three-tooth rooter.

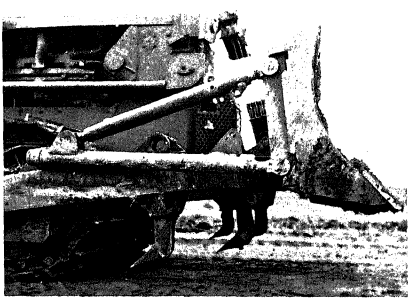


Figure 1-25. Back rippers.

1–29. Rear Mounted Ripper

The rear mounted ripper may have one or more shanks mounted on a tool bar hinged to the rear of the tractor (fig. 1–26). The down pressure characteristic is achieved from the hydraulic ram working between the tractor and the tool bar, thus applying a portion of the tractor weight to increase the down pressure. These rippers are primarily used for the same purpose as other type rippers but have better capabilities, since they can also do jobs where rooters normally are used, depending on the size of the ripper tooth and tractor. The attachment of the rear mounted ripper to the tractor does not seriously affect the maneuverability of the tractor, as the overall length is only increased 30 to 40 inches. The ripper can be raised out of the way while normal dozer operations are in progress, and returned to operating position by the manipulation of a control lever to resume ripping operations. Some ripper teeth are also vertically pivoted to permit individual teeth to move around small obstacles contacted beneath the surface. Since the rear mounted rippers are mounted in place of the draw bar, the tractors with rippers can not be used to tow attachments.

1–30. Rooter-Ripper Utilization

Most common usage of the rooter is in breaking hard materials for subsequent scraper loading. In this operation, the rooter will handle almost anything from sun-baked clay to soft rock. The limiting factors are, basically, the ability of the teeth to penetrate, and the available tractor power. Even in materials that could be handled by big scrapers without prior breakage, considerable savings can result from rooting. Jobs for the rooters are numerous.

a. It will quickly rip old blacktop pavement too tough for efficient scarifier or dozer work.

b. With old concrete, the tooth is started under the edge of the slab and pulled forward until the tractor is near stalling. Then the hoist is used to raise the tooth and break the slab, employing a lever action.

c. During clearing operations, a few passes to cut heavy main roots make even the biggest trees light work for a dozer. Here, again, the lift may be needed to assist tractor pull.

d. Having cut roots around a big stump, hooking a tooth under it and using the lift will in many cases pull it clear, forestalling the necessity of digging it out with a dozer.

e. Tangled root structures can be removed

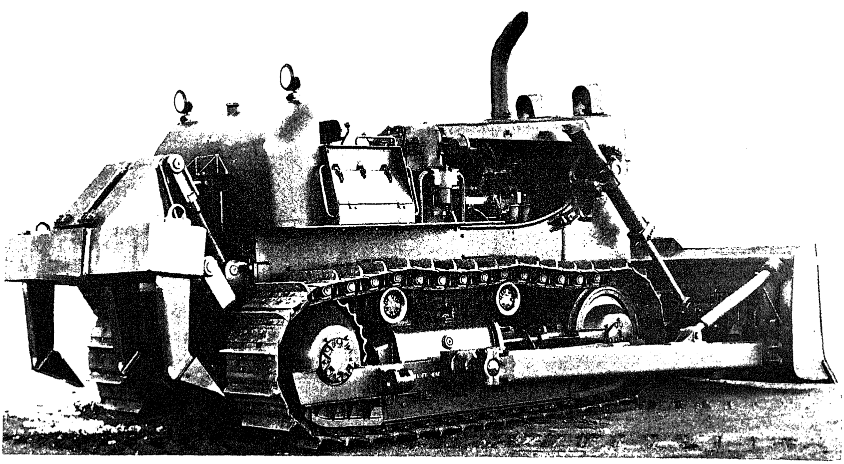


Figure 1–26. Rear mounted ripper.

by using a three or five toothed rooter raking to full depth in two directions at right angles to one another. As the teeth become loaded, they should be raised, bringing the accumulated roots to the surface.

f. Experience has shown a few simple rules for best results with rooters:

(1) Root to full depth of the rooter shank (fig. 1–27), removing shanks if available tractor power is insufficient. When using only two shanks of a three-toothed rooter, remove the center one. If using only one, leave the center shank.

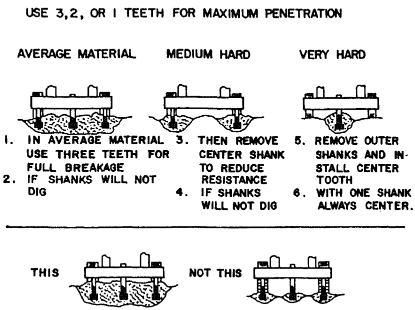


Figure 1–27. Rooting procedure.

(2) When turning, raise the shanks from the ground to avoid putting unnecessary twist on shanks and rooter's body.

(3) For extra penetration, ballast the rooter body. The weight or down pressure from the dozer blade of a pushing tractor is one way to get extra weight in a hurry.

(4) When starting to rip, start next to the slope line and work inward toward the center. This will help keep the cut low on the sides and crowned in the middle.

(5) When ripping rock, watch the strata (or grain). Always work against the grain from the exposed end.

(6) When rooted material is to be loaded in scrapers, the rooter completes the ripping operations before the scraper starts to load (fig. 1–28).

Section VII. GRADERS

1–31. Physical Characteristics of Graders

Graders are multipurpose machines used for grading, shaping, bank sloping, and ditching, and for general construction and maintenance of roads and runways. The physical characteristics of graders available for military con-

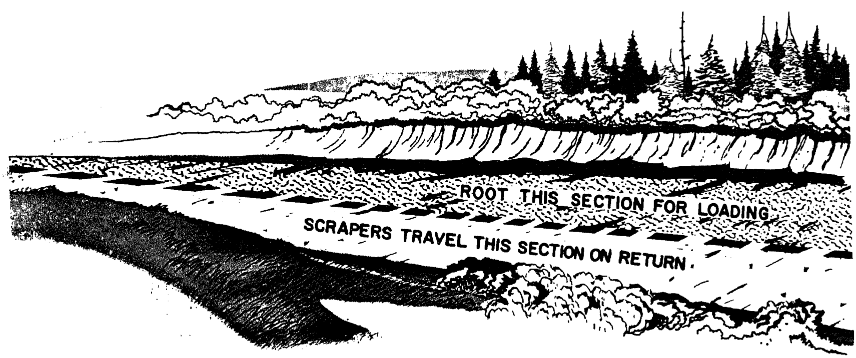


Figure 1–28. Rooting by sections.

Table 1–6. Characteristics of Graders

Make	Model	Height: Less cab	Height: With cab	L	W	Road speed: mph @ rated rpm — Forward gears: 1st	2d	3rd	4th	5th	6th	7th	8th	Reverse gears: Low	High	BHP
10′ moldboard w/scarifier 7,000 to 8,975 dbpp.	Diesel No. 212.	7′–0″	9′–6″	21′–11″ (TD)	6′–9½″	2.0	3.1	4.9	11.9	x	x	x	x	2.8	x	50@ 1,750 rpm
Caterpillar, (air-dropable).	......	......	......	21′–0″ (SD)	6′–4½″											
12′ moldboard w/scarifier 9,000 to 12,475 dbpp: Caterpillar.	Diesel No. 112.	7′–4″	9′–9″	24′–11″ (TD)	7′–10″	2.1	3.0	4.0	5.0	11.2	16.0	x	x	2.8	4.0	75@ 1,800 rpm
12′ moldboard w/scarifier Adams (LeTourneau Westinghouse)	Diesel No. 440 HA.	7′–8″	10′–6″	25′–9″ (TD)	7′–8″	2.7	4.4	6.9	11.4	19.2	29.4	x	x	2.1	15.1	131@ 2,000 rpm
12′ moldboard w/scarifier Adams (LeTourneau Westinghouse) (air droppable)	330HA	7′–5″	......	25′–10″ (TD)	7′–7″	2.7	4.3	7.2	11.6	18.9	32.7	x	x	2.1	15.1	85@ 2,000 rpm
Adams (LeTourneau Westinghouse) Air-transportable, air-dropable, GMC motor 353	Diesel No. 220	6′–8½″	......	25′–10″ (TD)	7′–6″	2.6	4.0	5.6	7.7	22.0	x	x	x	3.5	x	67@ 1,800 rpm
12′ moldboard w/scarifier; 12,500–14,475 dbpp: Caterpillar.	Diesel No. 12.	7′–5″	9′–10″	25′–10″ (TD)	7′–6″ (TD)	2.3	3.6	5.5	8.5	12.0	19.9	x	x	2.7	x	115@ 1,900 rpm
Huber Warco	Diesel No. 4D	7′–7″	10′–9″	adj to 25′–10″	8′–0″ (TD)	2.6	3.55	5.06	xxx	x	x	x	21.6	3.78	5.18	115@ 1940 rpm

* Engine maximum brake horsepower at full load rpm.

Note. (TD) Tandem Drive. (SD) Single Drive.

Scarifier teeth are interchangeable between graders.

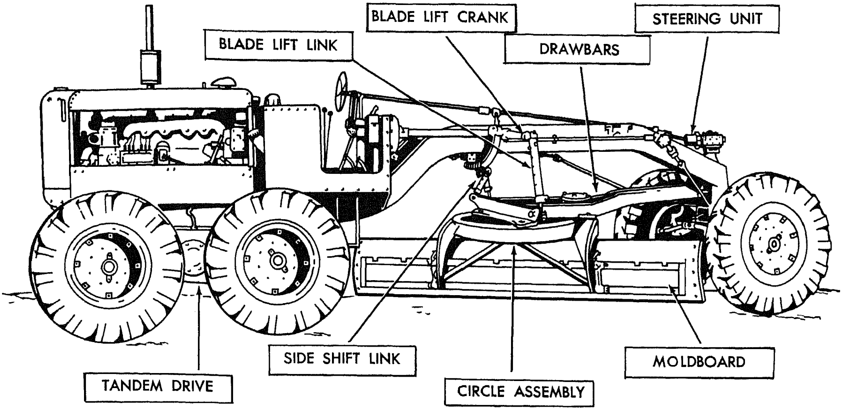


Figure 1–29. Motorized grader.

struction and maintenance activities are shown in table 1–6. When properly used, the grader can be employed for leveling and crowning, mixing and spreading, ditching and bank sloping, and sidecasting material. It may also be used for light stripping operations, but it is not intended for heavy excavation. These functions are performed by the moldboard or blade (fig. 1–29) and scarifier of the grader. The moldboard side casts the material it encounters while the grader maintains a continuous forward motion. Utilizing this method the grader can move a tremendous amount of material. The grader is capable of progressively cutting ditches to a depth of 3 feet. The moldboard of the grader can be positioned at any angle desired, within the limitations of the particular model (fig. 1–30). The structural strength and the position of the moldboard prohibit the use of the grader for dozer type work. It is restricted to shallow cuts in medium hard materials. When ditches deeper than 3 feet are to be constructed, it is

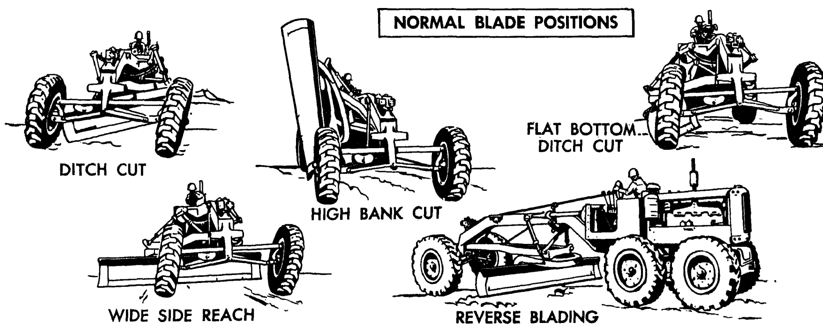


Figure 1–30. Grader normal blade positions.

more economical to utilize some other type of equipment. The grader is capable of working on slopes as steep as three to one, but it is not advisable to construct ditches running parallel on this slope as the grader has a comparatively high center of gravity which, coupled with the right pressure at a critical point of the blade, could easily roll the machine.

1–32. Blade Control Adjustments

The blade (moldboard) is controlled through a hydraulic or mechanical power system. The ends of the blade can be raised or lowered independently or together. It may be positioned perpendicular to the line of travel, parallel to it, or at any angle desired. It can be shifted to the side and into a vertical position (fig. 1–31). The pitch adjustment (fig. 1–32) on the moldboard is used to change the pitch on the cutting edge to produce a cutting or dragging action, whichever is desired by the operator. The blade ordinarily is kept near the center of the pitch adjustment so that the top of the blade is directly over the cutting edge. Increasing the lean forward decreases the cutting ability of the blade. When in this pitch position the blade will tend to ride over material rather than push it. In this position the blade has less chance of catching on solid obstructions. This forward pitch position is utilized when making light rapid cuts and blending materials. When leaned to the rear the blade cuts readily, but tends to let the material spill back over the blade.

1–33. Spreading

A grader blade may be used, to a limited extent, in spreading piles of loose material (figs. 1–33 and 1–34). If there is space to work around the sides of the piles, the blade should be extended well to the side and the pile reduced, using a series of side cuts. Piles to be spread by a grader should be spread dumped as much as possible when being placed. The load to be pushed is limited by the power and traction of the grader and will be much less than the load pushed by a crawler tractor of the same weight,

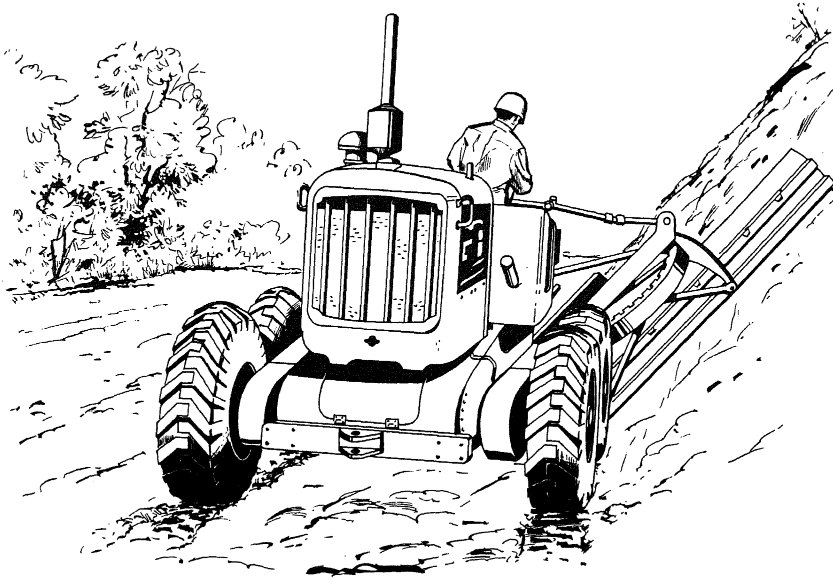


Figure 1–31. Sloping high bank with grader.

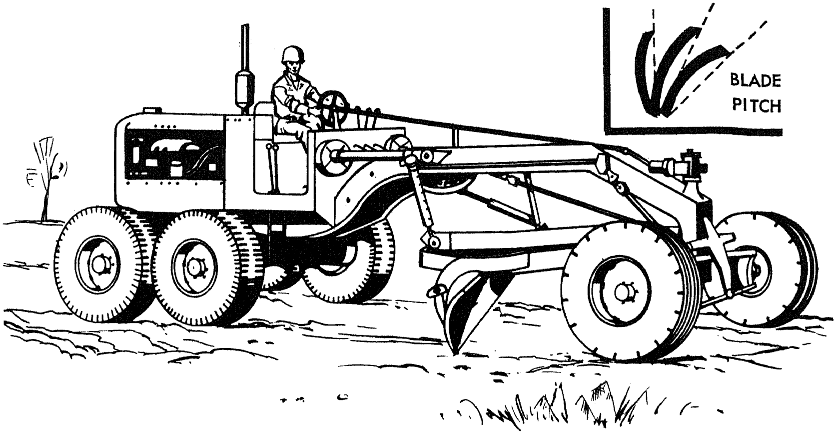


Figure 1–32. Grader blade pitch.

Figure 1–33. Grader spreading windrow.

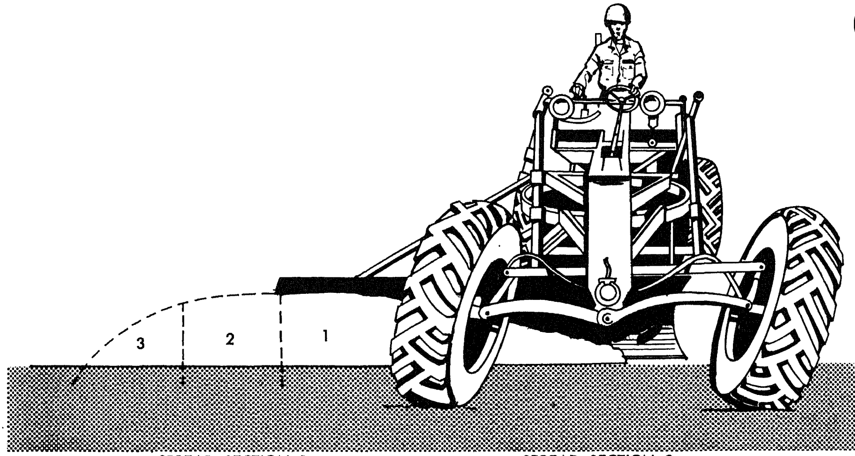


Figure 1–34. Leveling large windrows that require two or more passes with grader.

although it will be moved faster. The grader blade itself is quite low, but since it is more concave than the dozer blade it gives a more pronounced rolling action to the load, so that a large quantity can be pushed without spilling over the top.

1–34. Sidecasting

When the blade is set at an angle, the pushed load tends to drift off to the trailing end of the blade (fig. 1–35). The rolling action caused by the moldboard curve assists this side movement. As the blade is angled more sharply the speed of the side drift increases, so that material is not carried forward as far and a deeper cut can be made. The simple way in which to describe blade setting is to say that a blade set straight across, perpendicular to the line of travel, is at zero. All other settings are described by their angular distance from that position. Most road shaping and maintenance is done at 25° to 30° angle. This angle is decreased for spreading windrows, and increased for hard cuts and ditching.

1–35. Planing

If the blade is set at an angle, it can be used to plane off irregular surfaces by lowering them enough so that enough material will be cut off the humps to fill the hollows. Enough material should be cut to keep a partial load in front of the blade. The forward and sideward movement of the loosened material serves to distribute it effectively. If a windrow is left at the trailing edge of the blade it is picked up on the next pass. On the final pass a lighter cut is made and the trailing edge of the blade is lifted enough to allow the surplus material to go under rather than around it, to avoid leaving a ridge. Windrows should not be piled in front of the rear wheels as they will affect traction and grading accuracy.

1–36. Road and Ditch Construction Operations

Road and ditch construction is one of the basic operations of the grader. This operation normally is accomplished in the following steps.

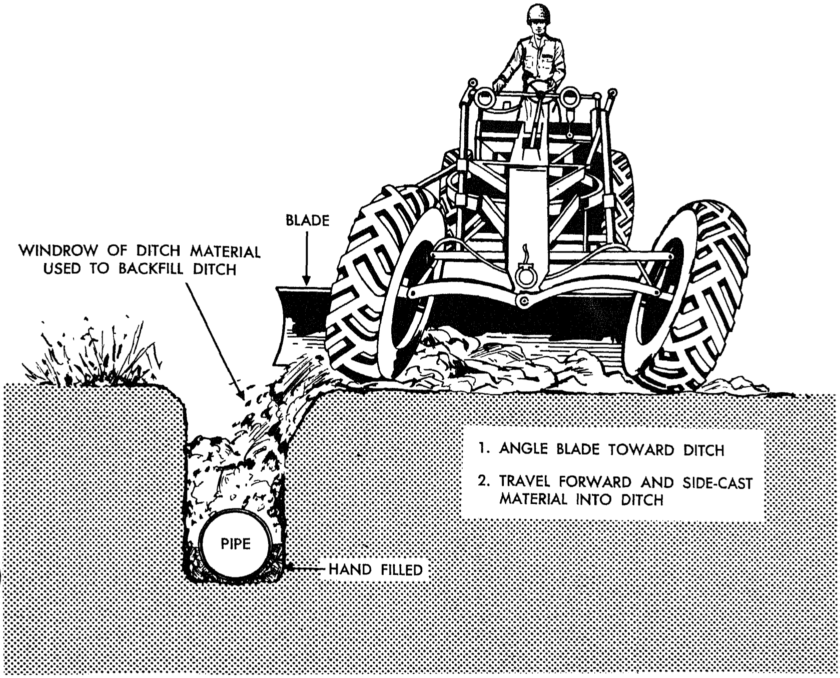


Figure 1–35. Backfilling a ditch by sidecasting.

a. Marking Cut. Better grader control is maintained and straighter ditches are achieved if a 3- to 4-inch deep marking cut (fig. 1–36) is made at the outer edge of the bank slope (usually identified by slope stages) on the first pass. This marking cut provides a guide for subsequent operations. The toe of the blade is in line with the outside edge of the lead tire.

b. Ditching Cuts. Each ditch cut should be made as deep as possible without stalling or losing control of the grader. Normally, ditching cuts are done in second gear at full throttle. The blade is positioned so that the toe is in line with the center of the lead tire. Each successive cut is brought in from the edge of the bank slope so the toe of the blade will be in line with the ditch bottom on the final cut.

c. Moving Windrows. When ditch cuts are made, windrows should be formed between the heel of the blade and the left rear wheel. When the ditch is at the prescribed depth or the windrow reaches a height greater than the road clearance of the grader, the windrow must be moved and leveled off. The shoulder of the road is formed during this operation. When this operation produces more material than is required for the roadbed and shoulders, and it cannot be wasted over a fill as would be the case in a through cut, excess material is bladed into a windrow and hauled away.

d. Leveling Windrows. This operation forms the crown of the road. All material spills off under the blade as the material is leveled. There is no windrow at the heel of the blade.

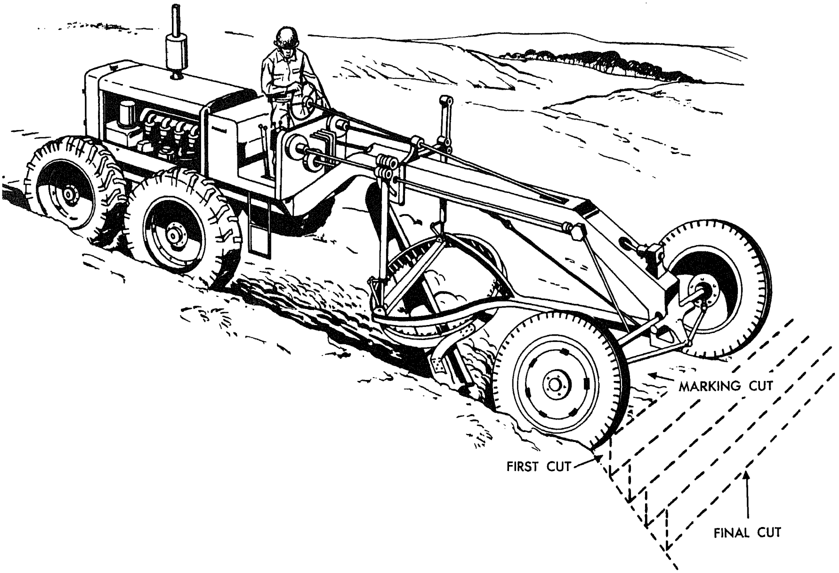


Figure 1–36. Starting a ditch with a grader.

e. Sloping the Bank Slope. This operation is necessary to prevent immediate or excessive erosion of the bank slope which would fill the ditch. When the bank slope is cut in steps, it is necessary only to smooth the ridges (fig. 1–37). If the ditching cuts have not been made as close to the design slope as possible, more than one pass may be required to bring the outer slope to final grade. The material cut from the outer slope is cast into the bottom of the ditch.

f. Cleaning the Ditch. To remove the superfluous material deposited in the ditch by the bank slope operation, the blade is placed in the same position as used for the ditching cuts, and casts the material onto the shoulder (fig. 1–38).

g. Finishing Shoulders. The windrow formed by cleaning the ditch is moved onto the road and, at the same time, the shoulder is finished to the desired slope.

h. Finishing Crown. The final operation is spreading all material on the crown brought from the ditch, and bringing the roadway to the desired crown.

1–37. Maintenance of Earth and Gravel Roads

Ordinary leveling and surface maintenance normally is done by working the material across the road or runway from one side to the other. To reduce the loss of binder by traffic and wind erosion, caution must be exercised when disturbing surfaces of dry roads. A satisfactory surface may be maintained in dry weather by working traffic-eroded material from the edges and shoulders of the road toward its center. Where binder is present and moisture content is appropriate, rough or badly pitted surfaces may be planed smooth by a cutting action and the surface material respread over the smooth base. The best time to reshape earth and gravel roads is after a rain. Dry roads may be watered down by the truck mounted water distributor. This insures that the material will have sufficient moisture content to recompact readily. When graders are used to correct corrugated roads, extreme care must be exercised so that

Figure 1–37. Sloping the bank slope during ditching.

the condition will be corrected rather than made worse. Deep cuts on a washboard surface will set up a blade "chatter" which emphasizes, rather than corrects, the corrugations. Scarifying may be required if the surface is too badly corrugated. With proper moisture content, the surface can be leveled by cutting across the corrugations. Alternate the blade so the cutting edge will not follow the rough surface. Cut the surface to the bottom of the corrugations and reshape the road surface by spreading the windrows in an even layer across the road. After the road has been reshaped it can be traffic compacted; however, better and longer lasting results are attained by rolling after shaping.

1–38. Bituminous Road Mixes

Mixed-in-place bituminous pavement is constructed by mixing bitumen with aggregate directly on the road where pavement is to be used. Where it is necessary to blend material with the scarified base to improve the gradation or increase the thickness, new material is dumped and spread evenly, either before or after scarifying. Where all the aggregate for the pavement is imported, the existing base is first shaped and prepared by any necessary blading, rolling, priming, and curing. Then the aggregate is dumped, mixed, and bladed into uniform windrows. If aggregate is too wet, it is necessary to work the windrows by blading to evaporate the excess moisture. The windrow is then flattened and bitumen is applied until the prescribed quantity has been added. After applica-

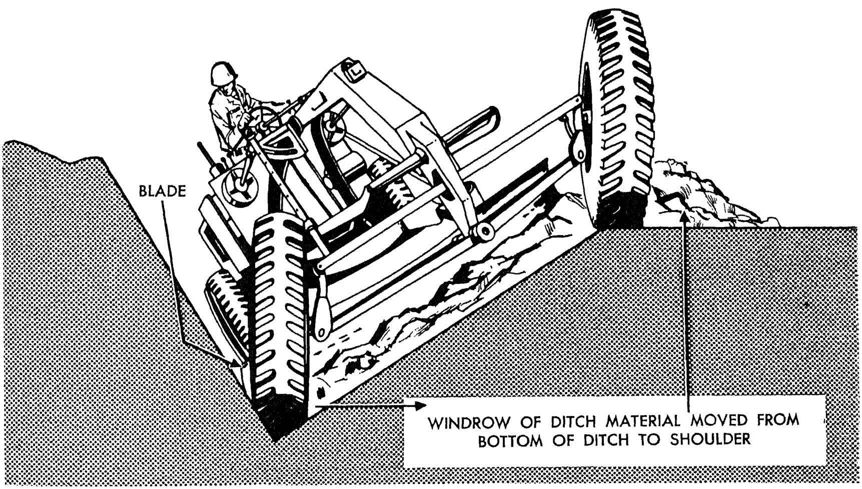


Figure 1–38. Ditching or ditch clearing with grader.

tion, mixing equipment follows to cover the bitumen and mix it with the aggregate. The mixing of each windrow is accomplished by graders. In mixing with graders, the windrow is moved from side to side by successive cuts with the blade. Several graders can operate, one behind another, on the same windrow. If the mixture is moistened by rain, mixing continues until the mixture is dry. After mixing, the material is again bladed into a windrow prior to spreading. Stakes are set to mark the edges of the spread from each windrow, and the mixed windrow is spread by graders. When mixtures are spread over large areas, blue top stakes are driven to indicate final elevation of the pavement. They are usually placed in a grid spaced 20 feet in both directions and are removed before the pavement is rolled. Usually the windrow is split with an angledozer or flattened with one pass of a grader. Then it is spread to each side in increments to produce a layer of uniform thickness and proper slopes laterally and longitudinally. Skillful grader operation is particularly necessary in this part of the operation.

1–39. Snow Removal

Graders can be used for snow removal in much the same way as snowplows. Care must be taken to raise blades ½ to 1 inch for plowing uneven pavements or portable runway surfaces. Improper adjustment can result not only in damage to the grader, but also in scuffing or gouging of the road. See TM 5–624 for proper methods of snow removal.

1–40. Scarifier

The scarifier is used to break up material that is too hard for the blade to cut. It is composed of a scarifier log, which is permanently fixed to the machine, and 11 removable teeth. The teeth can be adjusted to cut to a depth of 12 inches and the scarifier log can be adjusted for pitch. The pitching adjustment on scarifiers can aid in scarifying operations. With the top of the scarifier pitched to the rear, a lifting and tearing action is applied to the material being loosened. This position is used when breaking up asphalt pavement. The particular adjustment used would depend on what material one would be working in, and the action desired on the material. When operating in hard material it may be necessary to remove teeth from the scarifier log. A maximum of five teeth may be removed from the log. When removing teeth, take the center one out and then alternate removal of the other four teeth. This will balance the scarifier and distribute the load evenly. If more than five teeth are removed the force against the remaining teeth may cause them to shear off.

1–41. Grader Efficiency

The efficiency of any grader rests primarily with the operator, as each job has a specific blade setting and speed for optimum production. Any deviations from this setting and speed may be misinterpreted as machine inefficiency rather than operator error. Grader efficiency may fall off considerably when operating in wet and muddy conditions, obviously due to the poor traction. But sometimes the grader is used in such conditions in spite of reduced efficiency, as it is still the best item to use. One example of this would be casting the surface mud to the side of a haul road.

1–42. Proper Working Speeds

Operations are performed as fast as possible, consistent with the skill of the operator and the condition of the road. Operation in each gear is at full throttle. If less speed is required, a lower gear is used. Correct gear ranges for various grader operations generally will be as shown below:

Operation	*Gear*
Maintenance	2d to 3d
Spreading	3d to 4th
Mixing	4th to 6th
Ditching	1st to 2d
Banksloping	1st
Snow removal	5th to 6th
Finishing	2d to 4th

1–43. Obtaining Production Efficiency

a. Eliminating Turns. When a grader makes a number of passes over a distance of less than about 1,000 feet, it normally is more efficient to back the grader the entire distance to the starting point than to turn the grader around and continue work from the far end (fig. 1–39). Turns are never made on newly laid bituminous road or runway surfacing.

b. Number of Passes. Efficiency of grader work is in direct proportion to the number of

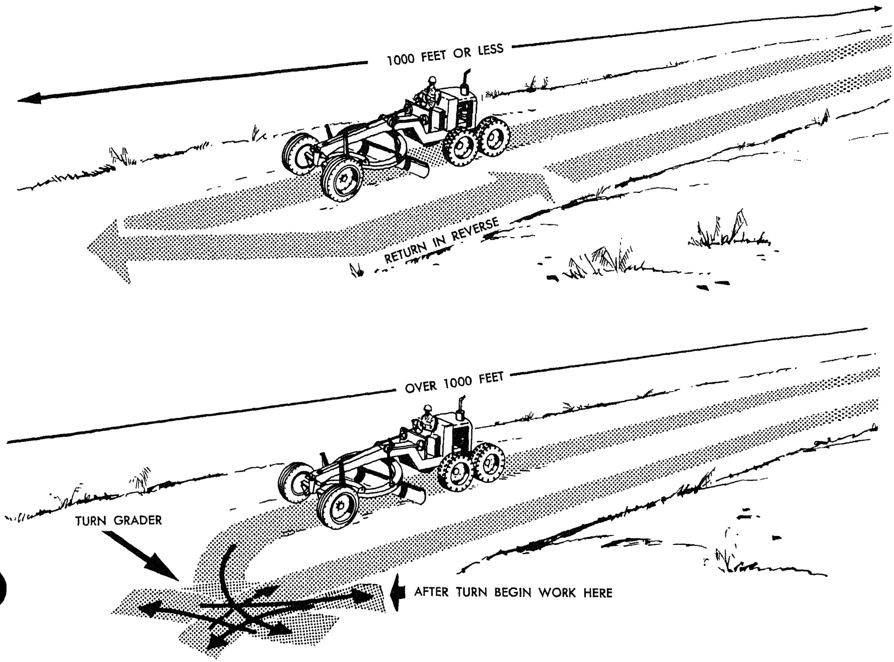


Figure 1–39. Eliminating unnecessary turns.

passes made. Operator skill, coupled with planning, is of utmost importance in eliminating unnecessary passes. For example, if four passes will complete a job, every additional pass increases the time for the job by 25 percent.

c. *Proper Tire Inflation.* Proper inflation of the tires of motorized graders is necessary to get best results. Overinflated tires mean a small contact area between the tires and the road surface with a resulting loss of traction. Differences of pressure in rear tires cause wheel slippage and grader bucking. The correct tire inflation for grader tires is given in the appropriate operator's technical manual.

d. *Maintenance of Haul Roads.* When scrapers, dozers, or dump trucks are performing a large earthmoving operation, efficiency is increased if the condition of haul roads permits high gear operation. Graders are the best machines for maintenance of haul roads.


Figure 1–40. Grading in reverse.

Table 1–7. Checklist for Grader Efficiency

Leveling	Ditching	Reshaping	Bank sloping	Scarifying	Mixing	Spreading	Snow removal
1. Is blade set at sharp enough angle to get proper slicing action?	1. Is marking cut made approximately 3 to 4 inches deep?	1. Is maintenance performed in least possible number of passes?	1. Is heel of blade at bottom of ditch?	1. Are teeth penetrating too deep so subgrade is torn up and mixed with road surface?	1. Is blade pitched forward to obtain rolling action?	1. Are there any signs that material is not thoroughly mixed?	1. Is grader speed high enough to throw material to one side?
2. Is blade set at proper pitch to get cutting action?	2. Is toe of blade directly behind front wheels?	2. Are shoulders and edges maintained to eliminate standing water?	2. Is blade set to give maximum slicing action?	2. If material is hard and consolidated, are enough teeth removed to give proper penetration?	2. Are graders worked in tandem where possible?	2. Is material being spread to proper thickness?	2. Has preliminary reconnaissance been made to locate any large heavy objects that may be hidden under snow?
3. Is blade set so windrow falls either inside or outside of rear wheels?	3. Is blade set so windrow falls inside of rear wheels?	3. Is material kept on road and not spilled into ditch?	2. Is bank sloping being done in first gear?	3. Is machine traveling as fast as power allows?	3. Is blade taking too much material, preventing free rolling?	3. Are wheels being turned on freshly spread mix, causing a wavy surface?	3. Is care being taken not to damage pavement or portable surface?
	4. Is windrow removed before it reaches underside of grader?	4. Is speed too fast or cut too deep, causing washboarding of surface?	4. Does the rear wheel trail heel of blade?	....	4. Is speed regulated to give proper mixing action and at the same time to allow full control of grader?		
	5. Is bank slope step-cut?	5. Is speed fast enough to maintain efficient operation?	....	....	5. Is blade set to produce a free flow of material?		
	6. Is the heel of the blade lowered to maintain inside slope of ditch?	6. Has operation been planned so flow of traffic is not stopped?					

e. Working in Tandem. The most efficient method of grader road maintenance is to use enough graders to complete one side of a road with one pass of each grader. In this way, one side of the road is completed while the other side is left open to traffic. Also, operations such as leveling, mixing, and spreading are expedited by using graders in tandem.

f. Grading in Reverse. A skilled operator can increase efficiency by grading in reverse if distances are long and turning is impracticable (fig. 1–40).

g. Efficiency. A checklist for use in determining the efficiency of grader performance is given in table 1–7.

Section VIII. PRODUCTION ESTIMATION

1–44. Considerations

The output of a piece of equipment depends on three factors: operational efficiency, equipment capacity (given in data tables), and cycle time. Production estimation is very important in determining the number of pieces of equipment required, the time of completion of the project, and the best way to utilize equipment on the job.

1–45. Operation Efficiency

Seldom does a unit ever reach maximum production. This may be due to several reasons such as supervisor's lack of knowhow, poor state of maintenance of the equipment, weather and terrain, and deficiencies in operator's skill and techniques. Thus the maximum production is multiplied by an efficiency factor to obtain the estimated production for this operation. This factor should be computed from past construction done by the unit. Where this factor can not be determined, the values given in table 1–8 can be used.

Table 1–8. Efficiency Factors

Time of operation	Type tractor	Working hours	Effcy factor
Day	Track-type	50 min/hr	0.83
	Wheel-type	45 min/hr	0.75
Night	Track-type	45 min/hr	0.75
	Wheel-type	40 min/hr	0.67

1–46. Cycle Time for Haul Units

Regardless of whether a water distributor (chap. 2) or a rubber-tired tractor-scraper is being used, it will require the movement through a regular cycle pattern—loading, hauling, dumping, and return—or some variation of it. Cycle time is the amount of time it takes an item of equipment to complete a circuit of these operations. Once an earth-moving project is laid out and is in operation, it is a fairly simple matter to estimate the cycle time of any particular unit on the job by timing several complete cycles of the equipment and then taking the average cycle time. Cycle time determines the number of trips per hour and it is evident that the supervisor will want to get as many trips per hour as possible. To do this, cycle time must be kept to a minimum. Failure to follow common sense practices usually results in low production figures and failure to accomplish construction in time. The engineer officer is commonly faced with the problem of predetermining his equipment requirements or utilization of available equipment before moving onto the worksite. By knowing the material capacity of the equipment and the power requirements and limitations of a given project the officer can accurately determine the cycle time of the equipment. From this, he can estimate production. Cycle time consists of two parts which are called *fixed time* and *variable time.*

a. Fixed Time. Fixed time is the time spent during an equipment cycle in *other* than hauling and returning. It involves the time for loading, turning, accelerating, decelerating, and dumping—all of which are fairly constant or fixed regardless of how far the material is hauled or carried away. Constants shown in table 1–9 have been determined by actual field studies that give the fixed time total for all operations described. These constants are intended to serve as guides only.

b. Variable Time. Variable time is hauling time or, more accurately, the time spent on the haul road transporting material and returning

empty. The time to do this varies with the distance to the fill and the speed of the hauling unit. It is found by the formula—

$$\text{Variable time} = \frac{\text{haul distance in feet}}{(\text{speed in mph}) \times (88 \text{ ft per min})}$$

Note. 88 is a conversion factor from mph to feet per minute.

Since speed is determined by power requirements and limitations and established by gear selection, it is common to haul in one gear and return in another. The variable time formula must be applied to *both* haul and return time.

1–47. Power Requirements and Limitations

A study of the kinds of power employed in earthmoving operations and the factors affecting each one will explain why the equipment can or cannot do the work. It will also explain how fast the equipment can travel under specified job conditions. This will give a means of fairly accurately estimating travel speeds and cycle time of equipment on proposed jobs and a method of checking production on existing projects. The available pull which a tractor can exert on a load is measured in pounds pull. In the case of a crawler tractor it is called drawbar pull, and a rubber-tired tractor's effort is called rimpull.

a. Drawbar Pull. Drawbar pull is the available pull which a crawler tractor can exert on a load. From the total pulling effort of an engine there must be deducted the pull required to move the tractor over a level haul road and the power loss due to friction of gear trains of the tractor. The result, after deducting these losses, is the power available at the drawbar and is classified as drawbar pull.

b. Rimpull. Rimpull was defined in paragraph 1–23*a* as the tractive force between the rubber tires of driving wheels and the surface over which they travel. The maximum rimpull is a function of the engine power, gear ratios between engine and wheel contact area, and friction power losses encountered in the gear train. If the rimpull of a unit is not known, it may be determined by the formula—

$$\text{Rimpull} = \frac{375 \times \text{engine horsepower} \times \text{efficiency}}{\text{travel speed in mph}}$$

The efficiency in the formula normally will range from 80 to 85 percent. Rimpull, unlike drawbar pull, is not the pulling power or the

Table 1–9. Fixed Time Constants

Wheeled tractor/scraper combinations	Basic fixed time constants for—		
	4th gear range	3d gear range	2d gear range
Loading (with pushers)	.7 min	.7 min	.7 min
Dumping and turning	.6 min	.6 min	.6 min
Acceleration and deceleration	.9 min	.7 min	.4 min
Total fixed time	2.2 min	2.0 min	1.7 min
Crawler dozers (shuttle dozing only):	Using the same transmission, shifting only with forward-reverse lever.	With the transmission shifted to higher gear when going in reverse.	
Total fixed time—one cycle	0.10 min	0.20 min	
Crawler tractor/scraper combinations.	Self-loading	Push-loaded	
Loading	1.5 min	1.0 min	
Dumping and turning	1.0 min	1.0 min	
Total fixed time	2.5 min	2.0 min	

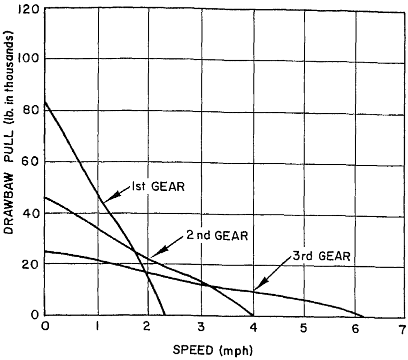


Figure 1–41. Drawbar pull vs speed for D7E crawler tractor.

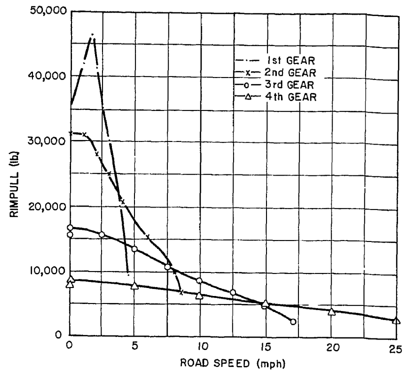


Figure 1–43. Rimpull vs speed for 290M rubber-tired tractor.

power that can be applied to the trailing unit. Power required to move the rubber-tired tractor must first be deducted from the rated rimpull and the remaining effort is then applicable to the trailing unit.

c. Power Versus Speed. The drawbar pull or rimpull will vary inversely with the speed of the tractor unit. Pulling power is greatest in first gear and lowest in the top gear. Equipment specifications, supplied by the manufacturer, normally list the maximum speeds and drawbar pull obtainable in each gear. Power versus speed figures for most tractors are given in table 1–3. The D7E and HD16M crawler as well as the 290M and 830M wheeled tractors are equipped with torque converter type transmissions. The power versus speed figures for these tractors are best portrayed in graphs as shown in figures 1–41, 1–42, 1–43, and 1–44, respectively. As an example, entering figure 1–41 with a required pulling power of 20,000 DBPP and following across to the gear range curves, it can be seen that while the D7E can pull the load in all three gears, the speed attained in 2d gear will be approximately twice that attained in 3d gear.

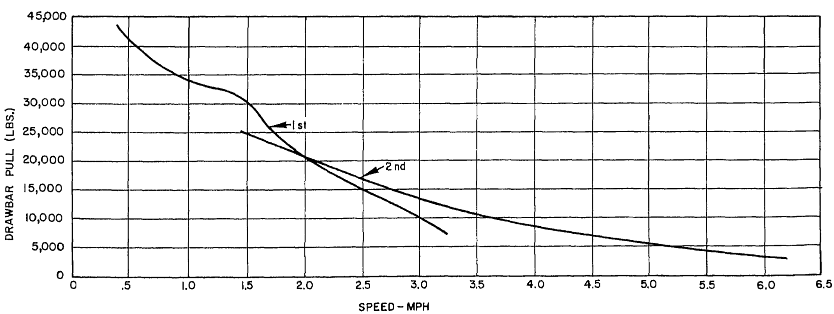


Figure 1–42. Drawbar pull vs speed for HD16M crawler tractor.

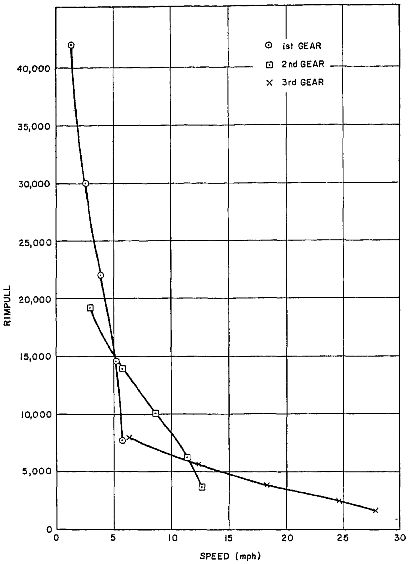


Figure 1–44. Rimpull vs speed for 830M rubber-tired tractor.

d. Power Required. Power required is concerned with the work to be done—a scraper to be pulled, a load to be pushed by a bulldozer, or some other job. The factors involved are *rolling resistance* and *grade resistance.*

(1) Rolling resistance is the retarding force of the ground against the wheels of a vehicle as the wheels penetrate the traveled surface. The force must be overcome before the vehicle will move, and constantly exists during travel in varying degrees. Many things determine rolling resistance. Some of the more important influences are internal tire friction, tire flexing, penetration into the surface, and weight on the wheels. By virtue of much trial and error, a rule of thumb has been developed to estimate the effect of these constants. This effect, measured in pounds pull, amounts roughly 2 percent of the gross vehicle weight. This means that 40 pounds of pull or push is required to move 1 ton of weight on wheels. This value is the rolling resistance factor of a wheeled vehicle traveling on a hard, smooth, level road with no wheel penetration, such as a concrete highway. Wheels penetrating to greater depths have greater rolling resistance to overcome. For practical purposes, five general factors have been established for estimating rolling resistance. Intermediate factors can be established by interpolation and practical experience. Typical rolling resistance factors are given in table 1–10. With the foregoing information, it is possible to determine the power required to overcome the rolling resistance of rubber-tired units. The formula for rolling resistance becomes—

Rolling resistance = weight on wheels (in tons) × rolling resistance factor (in lb/ton)

(2) Grade resistance must also be considered when determining power requirements. Grade resistance is the force of gravity which must be overcome when going uphill. It acts against the total weight of any vehicle, whether it is a track type or wheel type. When the grade is uphill or adverse, the effect is a demand for more power. Grade resistance is then a hindering force. If the grade is downhill or favorable, the effect is a helping force, tending to produce additional pounds pull to propel the equipment. This downhill effect is commonly called grade assistance. Grade resistance and grade assistance are estimated in the same way. Each 1 percent of grade produces a hindering or helping force of 20 pounds per ton of vehicle gross weight. The formula can be expressed as follows: GR (or GA) = total weight (in tons) × 20 lb/ton × units of % grade

(3) The total power required to move a unit is the algebraic sum of grade and rolling resistances.

(*a*) When traveling uphill a vehicle must overcome rolling resistance and grade resistance.

Table 1–10. Typical Rolling Resistance Factors

A hard, smooth stabilized roadway without penetration under load (concrete or black top).	40 DBPP/ton
A firm, smooth-rolling roadway flexing slightly under load (macadam or gravel-topped road).	65 DBPP/ton
A rutted dirt roadway, flexing considerably under load (hard clay road, 1 in. or more tire penetration).	100 DBPP/ton
Rutted dirt roadway, no stabilization, somewhat soft, under travel (4 to 6 in. tire penetration).	150 DBPP/ton
Soft, muddy, rutted roadway, or in sand.	200 to 400 DBPP/ton.

In the absence of the above data the following formula may be used:

Rolling resistance factor = 40 lb/ton + 30 lb/ton per inch of tire penetration.

Thus:

Total resistance = RR *plus* GR

(*b*) When traveling over level terrain a vehicle must overcome rolling resistance only.

Thus:

Total resistance = RR

(*c*) When traveling downhill a vehicle must overcome rolling resistance less grade resistance.

Thus:

Total resistance = RR *minus* GR (in this case GA)

e. Determining Tractor Speeds. The pounds pull required (rolling resistance plus or minus grade resistance) must be matched against the pounds pull available (taken from the specification sheets) and then a reasonable operating gear selected.

Example. The sum of the rolling resistance and grade resistance that a partcular wheel type tractor and scraper must overcome on a specific job has been estimated to be 7,100 pounds. What speed of travel is possible? The following data has been secured from the specification sheet (preferably) or from table 1–3.

Specification for Wheel Tractor

Gear	Speed (mph)	Pounds rimpull Rated	Pounds rimpull Maximum
1	2.3	22,560	27,330
2	4.5	11,760	14,240
3	7.2	7,300	8,840
4	11.7	4,530	5,490
5	18.8	2,810	3,401

Third gear, 7.2 mph, would be selected since the rated rimpull is 7,300 pounds. The reserve rimpull of the maximum rating is always available, at a reduced speed, to pull the unit over bad spots.

Note. Rated and maximum pounds pull are differentiated by classifying the rated pounds pull as the pounds pull available with the engine developing full rated horsepower at rated rpm. The travel speed on the equipment specification sheet corresponds to this rated pounds pull. The maximum pounds pull is the result of engine lug, but is available at lower travel speeds.

f. Power Limitations. Having determined the gear selection and travel speed, the limits imposed by actual job conditions should be investigated. In other words, is all the available specification sheet power actually useable power? To determine this, traction and altitude must be understood.

(1) Traction is the gripping action of wheels or tracks against the surface of the ground. Traction is always a limitation on power. The gripping action between tracks (or wheels) and the surface varies according to the weight on the tracks (or wheels) and the type of surface over which the vehicle travels. When tracks (or wheels) spin, there is poor or insufficient traction. If this is the case, one of two things may be done: Add more weight, and/or improve underfoot conditions. No tractor of existing design can exert more pounds pull than the weight of the equipment or the weight applied to the equipment. The weight on the driving wheels places a limit on the pulling force. Weight distributions are listed in manufacturers' specifications. In addition, weight distributions for tractor-scraper combinations common in the military are listed in table 1–11. For instance, a four wheel tractor, two wheel drive, towing a two wheel scraper, has approximately 40 percent of

Table 1–11. Weight Distribution of Common Tractor Combinations

Make	Model	Tractor front (lb) (%)	Tractor rear (lb) (%)	Scraper (lb) (%)	Total	% of load transferred to tractor wheels
MRS	100B w/7.5 cu yd Murray scraper	12,900 48	6,660 25	7,200 27	26,700 100	40
Caterpillar	830M w/18 cu yd Curtiss Wright scraper	38,280 45	24,980 29	21,500 26	84,760 100	40
Caterpillar	830M w/18 cu yd Euclid scraper	39,710 46	36,890 43	9,100 11	85,700 100	43
Caterpillar	830M w/18 cu yd Le Tourneau Westinghouse scraper	38,370 46	25,730 31	19,960 23	84,060 100	40
Clark	290M w/18 cu yd Euclid scraper	40,510 46	37,830 43	9,100 11	87,690 100	43
Clark	290M w/18 cu yd Le Tourneau Westinghouse scraper	39,170 46	26,920 31	19,960 23	86,050 100	40

Note. Weights as shown are with empty scraper.

the unit's gross weight on the drive wheels. Then the total force it can exert is primarily limited to 40 percent of the unit's gross weight. A specific type of underfoot condition expressed as "coefficient of traction" or "coefficient of friction" further limits the power that can be exerted. The coefficient of traction or friction is the gripping action between the drive wheels and the surface of travel. Typical coefficients of traction for use in production estimation are given in table 1–12. In determining the amount of useable pounds pull, the following formula is used:

Useable pounds pull—(coefficient of traction) × (weight on drive wheels)

Example: What is the maximum useable rimpull of a DW–21 and a loaded 18-cubic yard scraper operating in firm earth? Total weight of the unit is 112,000 pounds with 52 percent of this load on the drive wheels.

Useable pounds pull = (0.52 × 112,000) × (0.50) = 29,120 pounds

If the power required (sum of grade resistance and rolling resistance) is available (manufacturer's power specifications) and is less than the traction limitation, then the tractor can readily tow the load. On the other hand, if the traction limitation is less than the power required and available, then the tractor will be unable to tow the load and the tractor wheels or tracks will spin in place.

(2) As the location of an earthmoving job increases in elevation, the reduced atmosphere causes a reduction in engine horsepower. This has a proportional limiting effect on the available power *in any gear*. However, since the gearing of the power train does not change, the speed of the equipment remains as specified, but the rated drawbar or rimpull is reduced and must be evaluated. For altitudes above 3,000 feet elevation (5,000 feet for turbocharged or supercharged engines) a 3 percent loss of horsepower (DBPP or RP) is encountered for each 1,000 feet thereafter. For performance estimating purposes, it is advisable to make a complete derated drawbar

pounds pull table in each gear for the particular piece of equipment being used.

Example: For a D–8 tractor being operated at 10,000 feet elevation:

Gear	*Speed mph*	*lb pull rated*	*lb pull derated (21%)*
1	1.5	39,150	30,930
2	1.9	30,900	24,410
3	2.8	21,000	16,590
4	3.8	14,120	11,150
5	5.2	9,490	7,500

Example Problem. A project requires the building of an earth fill dam. How many workdays at 10 hours per day are required to complete the project? The job conditions are as follows:

(*a*) Compacted fill required ..... 100,000 cu yd
(*b*) Class of earth .... earth loam, dry
(*c*) Initial moisture content 10%
(*d*) Average haul distance ...... 8,400 ft
(*e*) Grade of haul road (to fill) .. +4%
(*f*) Type of haul road ..... Rutted clay loam, flexing under load, 1 inch or more tire penetration
(*g*) Elevation .... 3,000 ft
(*h*) Workday .... 10 hr
(*i*) Ten 830M tractors with Curtiss-Wright scrapers will be used (18-cu yd capacity).

Table 1–12. Coefficients of Traction for Tractors

Material	Rubber tires	Tracks
Concrete	.90	.45
Clay loam, dry	.55	.90
Clay loam, wet	.45	.70
Rutted clay loam	.40	.70
Loose sand	.30	.30
Quarry pit	.65	.55
Gravel road (loose not hard).	.36	.50
Packed snow	.20	.25
Ice	.12	.12
Firm earth	.55	.90
Loose earth	.45	.60

Solution:

Rolling resistance (RR)=gross weight of rolling unit in tons× rolling resistance per ton (table 1–10)

Weight of 830M=52,200 lb (table 1–3)

Weight of scraper=38,900 lb (table 1–5)

Total weight of empty rig= 52,200+38,900=91,100

Weight of load:

Scraper capacity=18.25 cu yd (table 1–5)

Weight of dry soil=1,950 lb/cu yd, loose (table 1–1)

Weight of soil with 10% moisture=1,950×1.10= 2,145 lb/cu yd

Weight of load= 2,145×18.25= 38,950 lb/load

Rolling resistance factor=100 lb/ton (table 1–10)

$$\text{RR empty rig} = \frac{91{,}100 \text{ lb}}{2{,}000 \text{ lb/ton}} \times 100 = 4{,}5555 \text{ DBPP}$$

$$\text{RR loaded rig} = \frac{91{,}100 \text{ lb} + 38{,}950 \text{ lb}}{2{,}000 \text{ lb/ton}} \times 100 = 6{,}500 \text{ DBPP}$$

Grade resistance (GR)=gross weight of rig in tons×20 lb/ton ×percent slope

$$\text{GR (to fill)} = \frac{91{,}100 \text{ lb} + 38{,}950 \text{ lb}}{2{,}000 \text{ lb/ton}} \times 20 \times 4$$

GR (to fill) =5,200 DBPP

$$\text{GR (return)} = \frac{91{,}100 \text{ lb}}{2{,}000 \text{ lb/ton}} \times 20 \times 4$$

GR (return) =3,644 DBPP

Traction limitation=weight on drive wheels×coefficient of traction

Weight on drive wheels=74% (table 1–11)

52,200 lb×.74=36,628 DBPP available

Coefficient of traction = 0.40 (table 1–12)

36,628 × 0.40 = 15,451 DBPP useable due to traction

Total pull required = RR (loaded) + GR =

11,700 DBPP required

11,700 DBPP required is less than 15,451 DBPP useable, therefore 830M can pull the load

$$\text{Haul time to fill} = \frac{\text{haul distance}}{\text{speed (mph)} \times 88}$$

DBPP required = 11,700

From figure 1–44, rimpull vs. speed for 830M rubber-tired tractor, using a rimpull of 11,700 pounds and reading for second gear, the speed is found to be approximately 7.5 mph.

$$\text{Time required} = \frac{88{,}400 \text{ ft}}{7.5 \text{ mph} \times 88} = 12.8 \text{ minutes}$$

Return travel time:

Return trip downhill, therefore GR (return) becomes Grade Assistance (GA) and must be subtracted from total pull required

DBPP required = RR empty − GA

DBPP required = 4,555 − 3,644 = 911 DBPP required

From figure 1–44 using a rimpull of 911 pounds and reading for third gear, the speed is approximately 30 mph.

Return travel time =

$$\frac{30 \text{ mph} \times 88}{8{,}400 \text{ ft}} = 3.2 \text{ minutes}$$

Total cycle time = haul time + return time + fixed time

Fixed time = 2.0 minutes (table 1–9)

(use 3d gear time as an average for estimating purposes)

Cycle time = 12.8 + 3.2 + 2.0 = 18.0 minutes

Production per day = number of loads per hour × volume of load × number of units × number of hours per day × efficiency factor

Efficiency factor = .75 (table 1–8)

$$\frac{60 \text{ min/hr}}{18.0 \text{ min/cycle}} \times 18.25 \text{ cu yd} \times 10 \text{ units} \times 10 \text{ hr/day} \times .75 = 4{,}562 \text{ cu yd, } \textit{loose}$$

Conversion factors:

in place to loose = 1.25 (table 1–2)

in place to compacted = .90

$$\frac{4{,}562 \text{ cu yd}}{1.25} \times .90 = 3{,}284 \text{ cu yd}$$ compacted per day

Time to complete project:

$$\frac{100{,}000 \text{ cu yd required}}{3{,}284 \text{ cu yd/day}} = 30.4$$ or 31 days required

1–48. Cycle Time for Dozers

Cycle times for dozers are similar to those for tractor scraper combinations. Normally, since a dozer moves a load short distances, the return is in reverse gear. Fixed time for dozers is assumed to be 0.10 minute if only the forward-reverse lever is changed when returning and 0.20 minute if the transmission speed is changed. For tractors with power shift transmissions the fixed time is negligible. In clay and hard material it is assumed that dozers will work in 1st gear when moving soil 100 feet or less and 2d gear for distances greater than 100 feet. For loose soils it is assumed that track type dozers will work in 2d and 3d respectively. The blade capacity is given in table 1–4. This capacity can be increased up to 200 percent by slot dozing or blade-to-blade dozing for distances greater than 50 feet, depending on the type of soil and the skill of the operators.

Example Problem: How many bank cubic yards of clay can be moved per hour using an HD6M tractor with straight dozer blade in shuttle dozing with an experienced operator when the average haul distance is 100 feet, the average return distance is 120 feet, and the dozer is operated in second gear forward and high gear reverse?

Step 1: Determine physical capabilities of dozer:

Blade capacity = 2.6 loose cubic yards (table 1–4)
Dozer efficiency factor = .83 (table 1–8)
Second gear forward = 2.4 mph (table 1–3)
High gear reverse = 5.5 mph (table 1–3)
Soil conversion factor = .70 loose to in place (table 1–2)

Step 2: Compute variable time:

$$\text{Variable time} = \frac{\text{haul distance (ft)}}{\text{mph} \times 88} + \frac{\text{return distance (ft)}}{\text{mph} \times 88}$$

$$= \frac{100}{2.4 \times 88} + \frac{120}{5.5 \times 88}$$

$$= .722 \text{ minute}$$

Step 3: Compute cycle time:

Fixed time = .2 minute (table 1–9)

Cycle time = fixed time + variable time
= .2 + .722 = .922 minute

Step 4: Estimate output:

$$\text{Output} = \frac{\text{blade capacity} \times \text{soil conversion factor} \times 60 \text{ min/hr} \times \text{efficiency}}{\text{cycle time}}$$

$$= \frac{2.6 \times .70 \times 60 \times .83}{.922}$$

$$= \frac{90.6}{.922}$$

= 98.3 bank cu yd per hour

1–49. Estimated Work Output of Graders

a. Work-Time Formula. The time required to complete a grader operation depends on the number of passes necessary and the spread maintained on each pass. In turn, this speed depends largely on the skill of the operator and the type of material handled. A work-time formula may be used to prepare preliminary estimates of the total time in hours required to complete a grader operation:

$$\text{Total time} = \frac{P \times D}{S \times E}$$

where: P = number of passes required
D = distance traveled in each pass in miles
S = speed of grader in miles per hour
E = grader efficiency factor

b. Factors in Formula.

(1) *Number of passes (P).* The number of passes depends on the operation and is estimated before construction begins.

(2) *Distance (D).* Distance traveled in each pass is expressed in miles and is determined before construction begins.

(3) *Speed (S).* Speed is expressed in miles per hour. It is the most difficult factor in the formula to estimate correctly. As work progresses, conditions may require that speed estimates be increased or decreased. The work output is computed for each operation that is performed at a different rate of speed. The sum of the values obtained in each part is the total required for the operation. Care must be taken to use the correct number of passes for each speed used. The operating speeds of graders are given in table 1–6.

(4) *Efficiency factor (E).* Grader efficiency factor takes into account the fact that a 60-minute work hour rarely is attained. Efficiency varies, depending on supervision, operator skill, maintenance requirements, and site conditions. The value of 60 percent used in the example, *c* below, is average. It must be verified or adjusted on each job by observation and experience.

c. Example Problem. Five miles of gravel road are to be leveled and reshaped by a grader with a 12-foot moldboard. Six passes are estimated to be required to complete leveling and reshaping. Type of material permits passes 1 and 2 in second gear (2.8 mph), passes 3 and 4 in third gear (3.4 mph), and passes 5 and 6 in fourth gear (5.4 mph).

Efficiency factor = 0.60

Substituting in work-output formula:

$$\text{Total time} = \frac{2 \times 5}{2.8 \times 0.6} + \frac{2 \times 5}{3.4 \times 0.6} + \frac{2 \times 5}{5.4 \times 0.6}$$

$$= 6.0 + 4.9 + 3.1$$

$$= 14 \text{ hours.}$$

CHAPTER 2

COMPACTION EQUIPMENT

Section I. TOWED COMPACTION EQUIPMENT

2–1. Introduction

Compaction means the pressing of soil particles together into a closer state of contact and in so doing expelling air or water from the soil mass. In other words, the problem of compaction is basically one of controlling the amount and size of pore spaces in soils. The primary objective of compacting soil is to obtain a density that will provide the desired strength and will carry specified loads without undue settlement and/or form an impervious barrier to the flow of water. On most jobs, a minimum desired density is specified. This density is referred to as a percentage of the maximum densities—compaction effort (CE 55) formerly designated as modified AASHO (American Association of State Highway Officials) methods.' Minimum densities required to be developed in the actual compaction on the project range from 90 to 100 percent of the laboratory test maximum. Formerly, specifications were written designating the depth of lifts, type and weight of rollers, number of passes of the roller, and roller speeds. The specifications could be faithfully followed by the construction supervisor, but the required densities were not obtained in all cases. Present day specifications require a specific density and it is the responsibility of the supervisor to obtain this density. Construction supervisors must be capable of obtaining these results with the least amount of effort, and must keep up with the earthmoving operation of construction. To accomplish compaction, various types of compaction equipment—sheepsfoot rollers, pneumatic tired rollers, steel wheel rollers, vibrating units, and others, all having their place—are used.

2–2. Sheepsfoot Roller

The sheepsfoot roller (fig. 2–1) consists of two main assemblies, the roller drum assembly and the roller frame assembly. The roller drum assembly consists of tamping feet welded on a hollow steel drum. The drums vary in size from the 42-inch diameter drums most common in the military, to the 73-inch diameter drums found in civilian industry. The feet are of various shapes and range in length from 7 inches to 18 inches. The tapered foot diminishes from the base of the shank to the sole, and may be round, square, or angular. The roller frame assembly consists of a box-beam frame to which "cleaners" are welded. The "cleaners" are mounted on the inside of the rear frame, and prevent "sticky" material from building up between the roller feet. These rollers are equipped with connector devices on the roller frame and may be made up into various width and depth combinations merely by connecting rollers together.

a. Oscillating Action. When assembling two or more rollers to be towed by a single tractor, horizontal hinge pins are used to connect the roller frame to adjacent frames. This permits each roller to operate partially independent of the roller abreast. The partial freedom of action derived from this system of connecting rollers permits equal distribution of tamping pressure on uneven ground surfaces.

b. Contact Area.

(1) A sheepsfoot roller is intended to shear and knead the soil and eventually to "walkout" leaving a compacted mass. If it does not penetrate little compaction will be gained. The roller is too light in this case. If it does not "walkout" the soil is merely being moved about and not compacted. The roller is too heavy in this case.

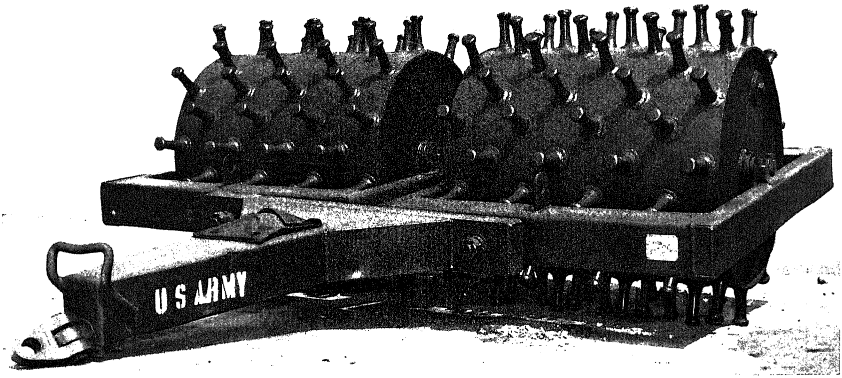


Figure 2–1. Sheepsfoot roller.

(2) Since the contact area of this type roller is relatively small, numerous passes are necessary to obtain maximum bearing pressure over a given area. As of the area of contact per foot is increased, the number of passes necessary to obtain complete coverage decreases. Tests on lean clay soils revealed that after a normal number of passes were accomplished there were still areas within the lift that were not compacted. Figure 2–2 correlates passes versus coverage.

c. Contact Pressures. Exerted bearing pressure can be varied by controlling the ballast in the hollow drums, or by attaching weights to the roller frame. This bearing pressure also varies with the size of rollers. For example, the following variations in bearing pressures can be made on the R. G. LeTourneau W–2 roller and American Steel Works MD–96 oscillating roller. (See table below.) Theoretically the bearing pressure will increase proportionally to the weight of the added ballast, but consideration must also be given to the increase in contact area of the roller as the roller tends to sink deeper in the lift due to the added weight. Tests conducted using 125 psi and 375 psi bearing pressure disclosed that when the higher pressure was used more feet,

Name	Drum diameter	Contact area of each foot	No. of feet on ground	Weight of two drums	Contact pressure
R.G. LeTourneau.	42 inches	5 1/16 sq in.	8	Empty 6,040 lb. W/water 10,240 bl. W/saturated sand 13,440 lb.*	149 psi 254 psi 333 psi
American Steel Works.	40 inches	5½ sq in.	8	Empty 6,200 lb. W/water 9,907 lb. W/saturated sand 13,243 lb.*	141 psi 225 psi 301 psi

* Caution should be taken when using sand as a ballast due to its tendency to stick and cake making removal difficult.

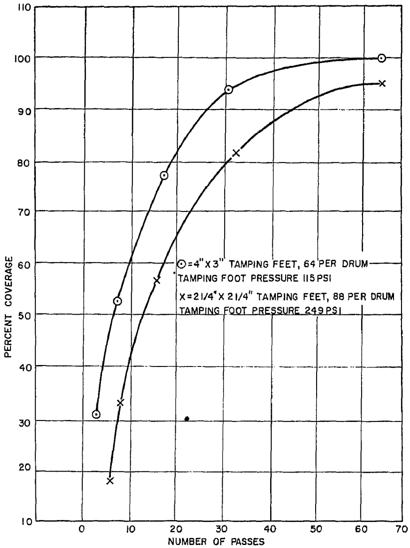


Figure 2–2. Number of passes versus coverage—sheepsfoot roller.

five or six rows, and a portion of the drum initially contacted the ground. As the roller walked out on succeeding passes, the contact area became less until only three rows of feet were in contact with the surface. Though the roller was ballasted to provide 375 psi when one row of feet was in contact with the ground, this pressure was not exerted during operation. It was evident from these observations that the higher pressure was exceeding the bearing capacity of the soil. This resulted in the feet penetrating into the soil until enough feet (or bearing surface) came into contact with the soil to reduce the unit load to a value equaling the bearing capacity of the soil. This test, on lean clay material, revealed that using 125 and 375 psi pressures, a maximum density of 93 precent CE 55 (modified AASHO) was obtained by both rollers, with 12 passes per roller.

d. Capabilities and Limitations.

(1) *Effect on soil.* The sheepsfoot roller is most effective on cohesive type soils; it is not recommended for compacting granular or noncohesive soils. Excessive pressures and small contact areas, a feature of the sheepsfoot roller, will shear noncohesive soils which depend on their frictional qualities for bearing capacity. Table 2–1 shows the contact pressure best suited for compacting different type soils.

(2) *Depth of lifts.* There is little evidence to indicate that increasing the length of tamping feet will permit more efficient compaction by the use of thicker lifts. Some increase in lift thickness is gained by increasing contact pressure

Table 2–1. Recommended Contact Pressures and Sizes of Tamping Feet for Sheepsfoot Rollers

Soil type	Contact area (sq in.)	Contact pressure (psi)	Remarks
Noncohesive, silty and clayey sandy soils which depend largely on their frictional qualities for developing bearing capacity.	7–12	75–125	These groupings are based on compacting to densities of about 95% CE 55 (AASHO) (T 99) maximum density at moisture contents slightly below optimum using 6- to 9-inch compacted lift thicknesses. Much heavier contact pressures may be more desirable if contact areas are increased. Such increases are necessary if higher field densities are to be produced.
Intermediate group of clayey silts, clayey sands and lean clay soils which have low plasticity.	6–10	100–200	
Medium to heavy clays.	5–8	150–300	

on larger feet, but stock models can seldom compact efficiently to depths greater than 10 to 12 inches.

2–3. Production, Sheepsfoot Roller

Specifications for compaction usually are given to the equipment supervisor by the engineer on the job after accomplishing test strip rolling. By knowing the depth of the loose layer of spread material and the number of passes established by the engineer, it is possible to estimate compaction production. The speed at which a tractor will pull a compactor depends upon the power requirements. The power required for pulling a sheepsfoot roller, in average loose material with 6-inch lifts, is approximately 600 pounds per ton of roller weight. For each adverse grade of 1 percent, add 20 pounds per ton of weight.

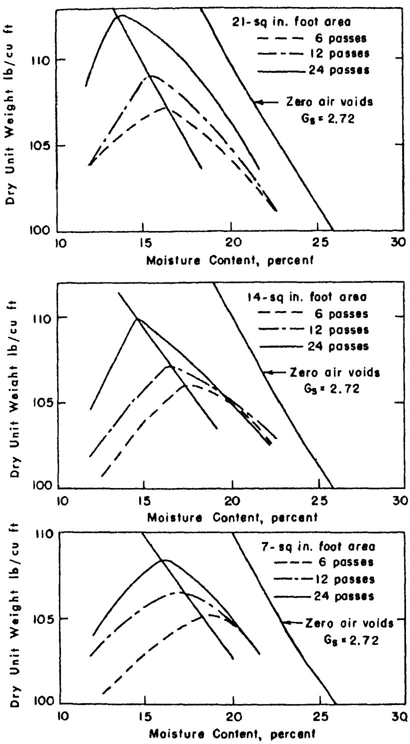


Figure 2–3. Passes and contact areas to produce densities.

a. Number of Passes Related to Densities Produced. The contact area and the number of passes determine the compactive effort applied to a soil and thus the densities produced. Figure 2–3 shows the effects of changing contact area and number of passes for a constant 250 psi contact pressure.

The soil type, even at optimum moisture, has a profound effect on the number of passes required to produce a given relative density. Figure 2–4 shows the compaction results of various soil types when compacted with a 12-square inch contact pressure of 115 psi.

b. Roller Radius. An additional factor influencing selection of the proper sheepsfoot roller is the rolling radius, because it determines in some degree the force required for towing as well as the roller's maneuverability. The smaller the rolling diameter (diam of drum plus ft) for a given weight, the greater the drawbar pull required.

c. Roller Action. If the roller walks up too fast and densities are inadequate, the lift thickness may need to be reduced or the bearing pressure increased, or both. Conversely, if the roller does not walk up or sinks deeper with an increasing number of passes, the shear strength of the soil is being exceeded and the bearing pressure needs to be decreased by removing ballast from the roller.

d. Roller Speed. Since increases in speeds, within reasonable limits, do not change the effectiveness of sheepsfoot rollers, the productive capability will increase as the roller speed is increased up to the point of tearing or displacing the material. This makes it worthwhile to consider speed when specifying roller hours.

2–4. Techniques of Operation, Sheepsfoot Roller

Sheepsfoot rollers are simple to operate, since they merely are pulled back and forth over the fill by the towing unit at a predetermined speed. It depends largely on the job whether the roller should be pulled forward over the fill, turning at each end, or pulled forward and reversed, or "backed-up," after reaching the end of the fill.

a. Overlapping Passes. To eliminate noncompacted strips, each pass with the roller should overlap the preceding pass by 1 foot.

b. Turns. When turning at the end of each pass, make gradual turns on the construction site area. This prevents tearing up the surface, eliminates the possibility of damaging the roller tongue with the tracks of the tractor, and also prevents the roller drums from binding.

c. Compacting Against Structures. When compacting against structures, satisfactory results can be obtained by running the roller parallel to the structure, if space permits. When compacting close to structures in confined areas best results can be obtained by placing fill material, sloped to the height of the roller axle,

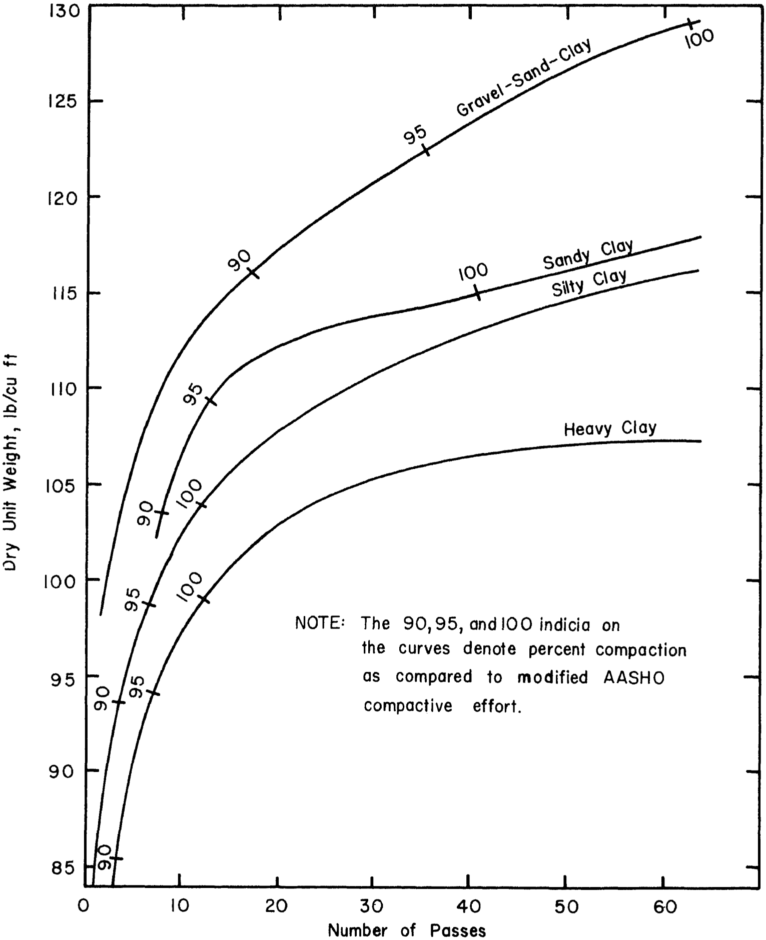


Figure 2-4. Number of passes vs soil type at optimum moisture contents.

against the structure and backing the roller against this fill.

d. Aerating Materials. When the roller is used to aerate soils, it should travel at the highest practical speed. This high speed tends to kick up the material so that the particles are exposed to the air for a longer time.

e. Working Edges of Deep Fills. The danger of compacting edges of deep fills may be partially reduced by adding a third drum connected to a dual drum system. This permits the roller to compact the edge of the fill, while the tractor traverses on solid footing.

2–5. Characteristics Common to Pneumatic Tired Rollers

a. Number of Passes. A characteristic of the pneumatic tired roller is the relatively large contact area in relation to the sheepsfoot rollers. One pass of the 13 wheel roller will make a thorough coverage of the area. The 13 roller does not exert compaction effort to any great depth but the 50-ton pneumatic tired roller will compact to depths greater than 18 inches. Fewer passes are required when using the 50-ton roller than when using the sheepsfoot roller, when compacting most types of materials.

b. Rolling Radius. The theory that a big wheel rolls easier and requires less drawbar pull than a small wheel has been instrumental in the selection of large diameter tires for the heavy rollers. Tires 5 to 7 feet, outside diameter, are commonly used.

c. Tire Pressures. Tire pressures must be varied when compacting different types of soils. Tests on a lean clay type soil revealed that tires having 90 psi pressure effectively compacted to a depth of 14 inches, whereas tires having 150 psi pressure effectively compacted to a depth of only 9 inches. This is attributed to the greater sinkage and rutting of the higher pressure tires in the loose soil. When making pressure selections, it must be considered that heavy rollers with high pressure tires require extra tractive effort, and possible precompaction with reduced tire pressure or with lighter rollers to prevent high initial sinkage and shoving in loose lifts. To achieve the maximum benefit from the 50-ton roller, the maximum tire pressure the soil can withstand should be used, and the maximum required load for that tire pressure. Increasing load, while maintaining the same tire pressure increases the roller's ability to compact in depth.

d. Roller Action. Pneumatic tire compactors provide a kneading action which tends to knit material into a denser mass.

(1) Surface and subsurface failures can be detected by closely observing the action of the wheels on the surface of the area being compacted.

(2) A continuous rutting of the surface indicates that the shear stress of the soil is being exceeded. The tire pressure or the load or both must be reduced to correct this.

(3) A ground wave action preceding and following the wheels indicates that an area beneath the surface is faulty. Before continuing compaction, this faulty area must be removed or corrected. If it is removed, suitable material must be replaced and compacted.

e. Roller Speed. The determination of roller speed is a controversial question. In civilian construction, some states specify that the roller speed will not exceed 5 mph, whereas other states specify the minimum speed will be 3 mph; some states advocate a maximum speed of 10 mph, while the majority of states make no comment on speed. The speed of the 50-ton roller normally will be determined by the available drawbar pull of the tractor and the rolling resistance of the terrain. The manufacturer of the 13-wheel pneumatic tired roller recommends towing speeds ranging from 10 to 15 mph. The speed of the roller should be determined on a test strip (para 2–21).

2–6. Pneumatic Tired Roller, 50-Ton

a. Familiarization. In the past decade, pneumatic tired rollers have steadily grown larger and heavier as compared to the multiple-wheel types which have been in use for years. It is now possible to obtain heavy pneumatic tired rollers of 50-, 100-, 150- and 200-ton gross weights, with a maximum wheel load of 50 tons. These rollers include single and dual axle types, oscillating units with two wheels per axle, and individually loaded wheel units. The 50-ton pneumatic-tired roller (fig. 2–5) has been adopted by the Army as a standard item of issue to construction units. The load box and frame are carried on four $16{:}00 \times 21$, 36 ply

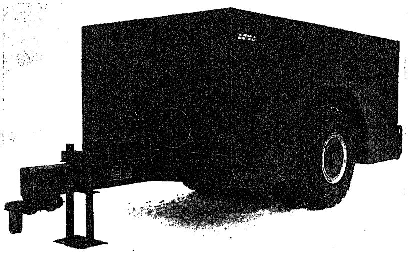


Figure 2–5. 50-ton pneumatic roller.

tires. Tires and wheels are mounted by pairs on common spindles which are allowed to oscillate about the trunnion shafts within the limits of the trunnion housing. Empty weight of this roller is 15,000 pounds. The weight ballasted with water is 59,000 pounds, or by using saturated sand the total weight will be 114,000 pounds.

b. Contact Pressures. The contact pressure of a pneumatic tired roller is determined primarily by the tire pressure. Within the rated load limits, the same load and tire pressure will give approximately the same contact area for any tire. Although the tire sidewalls do transmit some portion (10%) of the load essentially the entrapped air supports the load. Consequently, the tire will deflect until the contact area is sufficient that the pressure of the ground on the tire is equal to the pressure within the tire. Such analysis eliminates the size and characterisics of the tire from the equation. For instance, a tire with an internal tire pressure of 50 psi and a 5,000-pound wheel load will result in a contact area of 100 square inches. If the load is doubled to 10,000 pounds the tire will deflect until 200 square inches are in contact with the ground. Actually the tire sidewalls do carry a portion of the load and approximately 10 percent of the wheel load is transmitted through the sidewalls. Then

$$\text{Area of contact} = \frac{.90 \times \text{wheel load}}{\text{Tire pressure}}$$

Generally the raised portions of the tread are neglected in the analysis of contact pressure and the gross contact area (including areas beween the raised portions) is used to determine contact pressure.

$$\text{Contact pressure} = \frac{\text{wheel load}}{\text{contact area}}$$

Figure 2–6 gives typical empirical test results for a particular size tire relating tire pressure, wheel load and contact pressure.

c. Wheel Load. Test sections have been built in 6-inch compacted layers using wheel loads of 10,000, 20,000, and 40,000 pounds. It was anticipated that increased wheel loads would increase density. However, the same densities were obtained with the three different wheel loads. In these tests the tire-inflation pressure was maintained at a constant at 65 psi. The vertical pressure distribution for the tire loadings is illustrated in figure 2–7. As can be seen the difference in effective pressure varies with depth but the pressure differences between the three loads at shallow depths such as 6 inches was not significant to produce additional density. In this and other tests, it has been determined that an increase in wheel load is beneficial in compacting thick lifts. For example, the 10,000-pound wheel load would be exerting an effective pressure of approximately 10 psi at a 20-inch depth. A 40,000-pound wheel load would be exerting an effective pressure of approximately 30 psi or almost three times as much at the same 20-inch depth. Thus the wheel load is significant for compacting in depth or in test rolling to detect subsurface faults. Figure 2–8 shows the vertical stresses exerted by different sizes and pressures of tires.

d. Coverage. Surface coverage is determined by the wheel arrangement and the tire deflection. Figure 2–9 shows the results of varying wheel load and tire pressure on single pass coverage for a heavy pneumatic-tired roller. Most of the lighter pneumatic rollers use two rows of tires with the tires of one row offset in the gaps of the tires in the other row. This insures complete coverage with one pass. Heavier rollers require two passes for complete surface coverage. The additive effects of the pressure bulbs resulting from wheel on heavier rollers affect the in-depth coverage and consequently the rolling pattern. Figure 2–10 shows that the in-depth coverage would require considerable overlap with each pass to insure that the entire area has received the same compactive effort.

e. Speed. The speed of this roller is limited by the power required to overcome the rolling

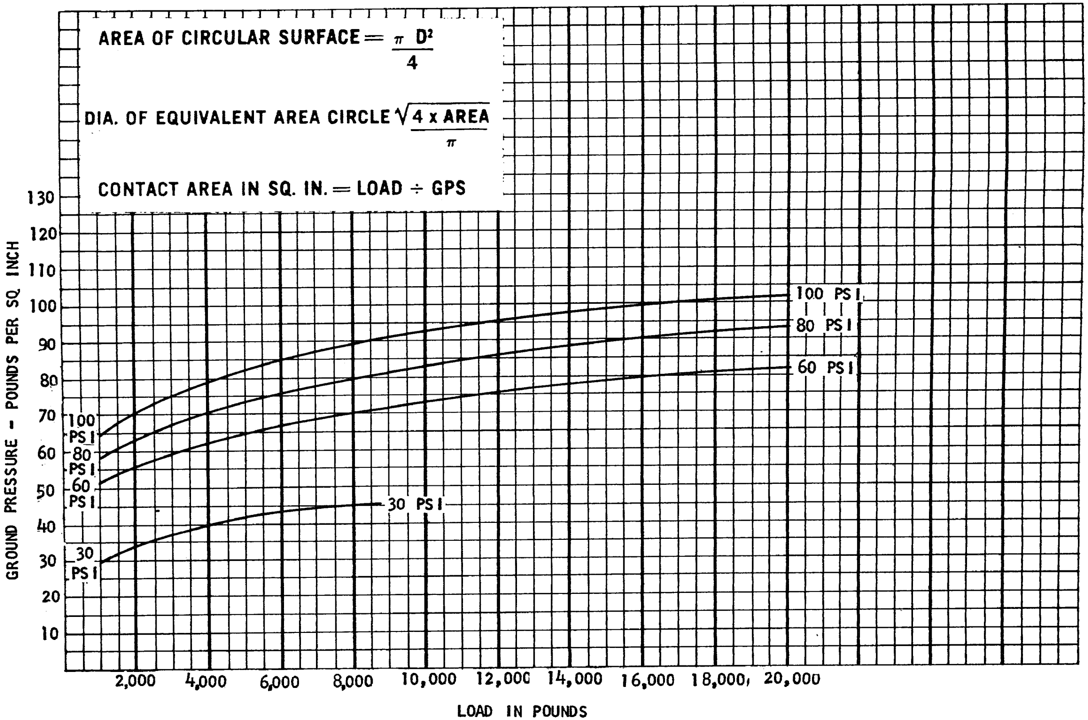


Figure 2–6. Ground pressure vs load for various tire pressures.

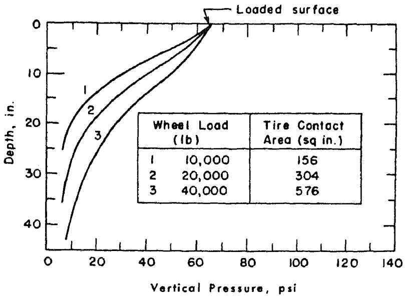


Figure 2–7. Pressure distribution beneath wheel load.

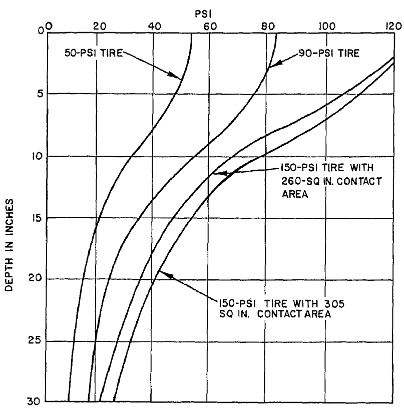


Figure 2–8. Vertical stresses.

resistance. When compacting loose lifts, the penetration of tires is greater during the initial stages of compaction than when the lift has been partially compacted. Thus, greater power is required during the initial stages of compacting loose lifts, and rolling speeds will be slower at this time. In determining the economy of compaction in thick lifts, the fact that heavy rollers with high-pressure tires require extra tractive effort and possibly precompaction with lighter rollers to prevent high initial sinkage and shoving in the loose lift, may outweigh the advantage of increase lift thickness. To determine the approximate power required to pull heavy pneumatic-tired compaction rollers, a knowledge of the conditions under which they will operate is necessary. The following will cover *most* operating conditions: [1]

Type of surface [2]	*Rolling resistance*
• A hard, smooth stabilized, surfaced roadway, without penetration under load, watered, maintained.	40 lb/ton

Type of surface [2]	*Rolling resistance*
• A firm, smooth, rolling roadway, with earth or light surfacing, flexing slightly under load or undulating. Maintained quite regularly. Watered.	65 lb/ton

Type of surface [2]	*Rolling resistance*
• An earth roadway, rutted, flexing under load, little if any maintenance. No water.	100 lb/ton
• Rutted earth roadway, soft under travel, no maintenance. No stabilization.	150 lb/ton
• Soft, muddy rutted roadway—or in sand. No maintenance.	200 to 400 lb/ton

Having determined the power required to move the roller, then through the use of tractor capability specifications (table 1–3), the forward speed of the roller can be predetermined.

2–7. Production, Techniques, 50-Ton Roller

a. Considering that a gap between tires leaves an unrolled area, two passes are required for a complete coverage.

b. If the roller gets bogged down when working in loose lifts, use a pusher tractor to assist in its removal. By using the lifting capability of the pusher tractor blade while pushing, the roller will be freed more easily.

c. Tires can be filled with water for added weight, but care must be taken during freezing weather to prevent damage to the tires. A mixture of water and calcium chloride will give the weight needed and will not freeze. Special inner tubes are required when using calcium chloride.

d. When moving from one jobsite to another, unload the ballast from the load box to prevent damage to the roads that have weight restrictions. Travel at slow speeds so that the towing

[1] For each 1 percent adverse grade add 20 lb/ton.
[2] For each 1 inch of penetration add 30 lb/ton.

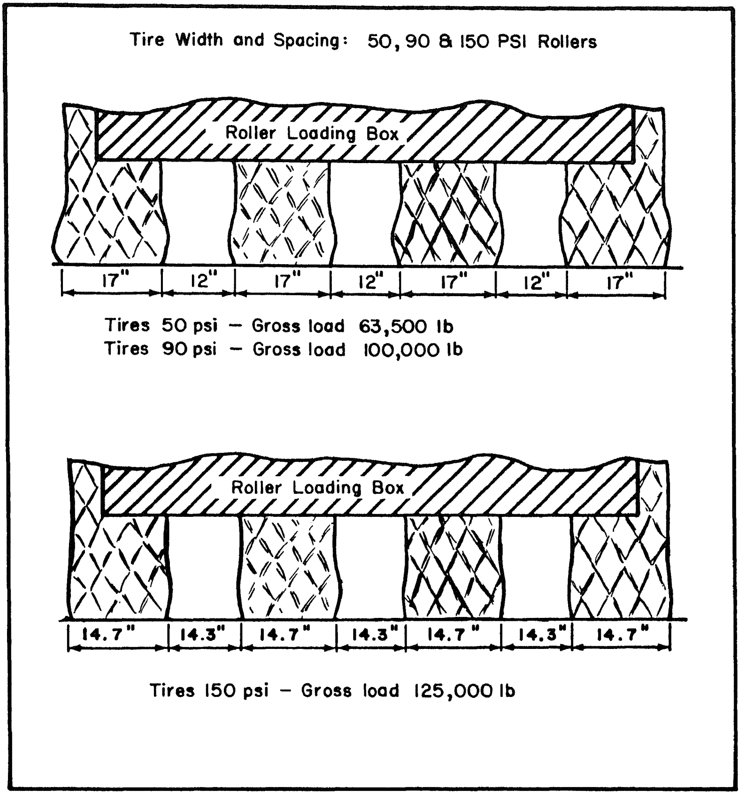


Figure 2–9. Diagram of coverage, 50-ton roller.

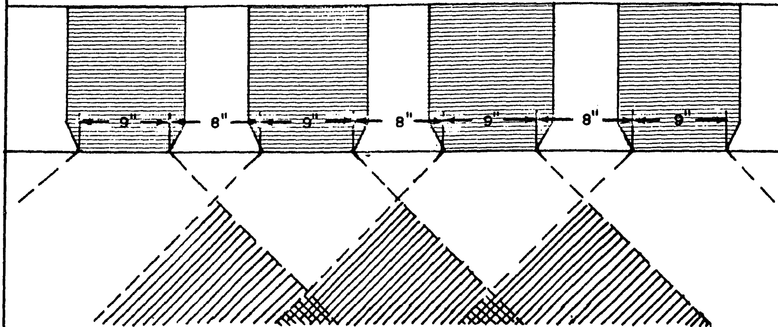
unit will have control over the roller. Since the roller has no brakes, its weight will tend to push the towing unit.

2–8. 13-Wheel Pneumatic Tired Roller

a. Familiarization. The 13-wheel roller (fig. 2–11) consists of an open-top drop center body with drain plugs located conveniently at the front and rear of the bottom. It rolls on 13 pneumatic tires, 6 forward and 7 to the rear, mounted in pairs with the exception of 1 wheel rigidly mounted in the rear line of wheels. The wheels of some makes and models are mounted on special offcenter hubs which produce a slight wobble which, in turn, causes the wheels to track in a wavy or irregular forward line. These rollers are designed to be towed by rubber-tired tractors or trucks. Recent commerical models are self-propelled.

b. Capabilities and Limitations. The open type body permits the use of sand, gravel, water, or other type materials for ballast purposes. The roller is capable of carrying loads up to 9 tons, but best compaction has been obtained

10.00 X 20 TIRE–14PLY – 90 PSI INFLATION – 6000 LB WHEEL LOAD
– 120 PSI INFLATION – 8000 LB WHEEL LOAD
GROSS CONTACT AREA 66 SQ IN.– EQUIVALENT CIRCLE DIA. 9.16"



PRESSURE AT VARIOUS DEPTHS

	90 PSI TIRES–6000 LB WHEEL LOAD			120 PSI TIRES–8000 LB WHEEL LOAD		
DEPTH INCHES	EQUIVALENT CIRCLE DIA.	AREA OF STRESS	PRESSURE PSI	EQUIVALENT CIRCLE DIA.	AREA OF STRESS	PRESSURE PSI
SURFACE	9.16 IN.	66.00 SQ. IN.	90.90	9.16 IN	66.00 SQ. IN.	121.21
1	11.16 "	97.82 "	61.34	11.16 "	97.82 "	81.78
2	13.16 "	136.02 "	44.11	13.16 "	136.02 "	58.81
3	15.16 "	176.71 "	33.95	15.16 "	176.71 "	45.27
4	17.16 "	231.28 "	25.94	17.16 "	231.28 "	34.59
5	19.16 "	288.33 "	20.81	19.16 "	288.33 "	27.75
6	21.16 "	351.66 "	17.06	21.16 "	351.66 "	22.75
7	23.16 "	421.28 "	14.24	23.16 "	421.28 "	18.99
8	25.16 "	497.18 "	12.07	25.16 "	497.18 "	16.09
9	27.16 "	579.37 "	10.36	27.16	579.37 "	13.81
10	29.16 "	667.83 "	8.98	29.16 "	667.83 "	11.98
PRESSURE IN SINGLE HATCH AREAS						
5			41.62			55.50
6			34.12			45.50
7			28.48			37.98
8			24.14			32.18
9			20.72			27.62
10			17.96			23.96
PRESSURE IN DOUBLE HATCHED AREAS						
13			30.90			41.20
14			27.65			36.90
15			24.90			33.20
16			22.55			30.05
17			20.50			27.35
18			18.75			24.95
19			17.15			22.90
20			15.80			21.05

Figure 2–10. Pressures at various depths.

with loads not exceeding 7 tons. Exhaustive tests have revealed that excessive loading tends to reduce or eliminate the basic compacting advantages obtainable with this unit. Straight or wobbly wheels may be mounted. The wobble action creates an additional kneading action which is very effective in compacting granular type soils. The staggered arrangement of wheels results in a complete coverage, 84 inches wide, with one pass of the roller. The draw pole can be adjusted to three different heights. This feature permits the attachment of the roller to drawbars of trucks or tractors having various heights. This roller may be used at speeds up to 15 miles per hour; however, soil conditions and the weight of the roller will limit the speed. When there is excessive penetration and insufficient clearance between wheels, the material being compacted tends to bulk up in front of the wheels and no compaction is accomplished. The roller is most efficient when compacting shallow lifts of granular type soils up to 6 inches.

2–9. Production Techniques, 13-Wheel Roller

a. Tire Pressure. When operating the roller with a rolling load of 7 tons or less, the tire pressure should be maintained at 25 psi. Increase the pressure 5 psi for each additional ton, up to the maximum load of 9 tons.

b. Towing Tractor. The 13-wheel roller should be towed by a rubber tired tractor, but can be connected to any tractor by the adjustable pole on the roller.

c. Towing the Roller. Best compaction results are obtained with a load of 7 tons or less. Greater loads tend to reduce or eliminate the kneading action obtainable with this roller, and the higher tire pressure results in faster tire wear and greater expenditure of power by the towing unit. The 13-wheel roller should be towed at speeds of 10 to 15 miles per hour on straightaways and 5 miles per hour on turns. Never tow the roller over rocks, curbs, or ditches, as this may damage the bolster swivel ball and socket joint.

d. Compacting Slopes. When compacting the bank sides of dams or canals, the roller can be hooked to a dragline and pulled up and down the steep slopes, giving thorough compaction of the area.

e. Controlling Cross Section. To control the cross section when rolling base and surface courses, begin rolling at the ditch line and work towards the centerline.

f. Turning. Do not turn the roller on the compacted surface unless absolutely necessary, and then turn as gradually as possible.

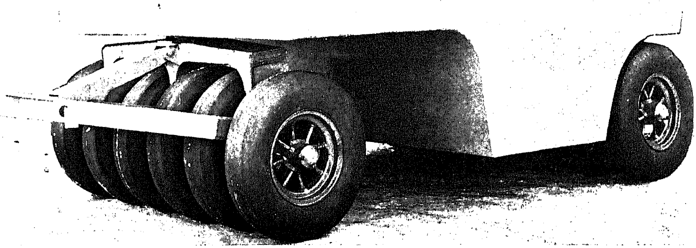


Figure 2–11. 13 Wheel pneumatic tired roller.

Section II. MOTORIZED COMPACTION EQUIPMENT

2–10. Two- and Three-Axle Tandem Rollers

The tandem type rollers have two or three rollers. Drive and guide rollers are the same width, but drive rollers are larger and provide about twice as much compaction effort as do the guide rollers. Engines are center mounted par-

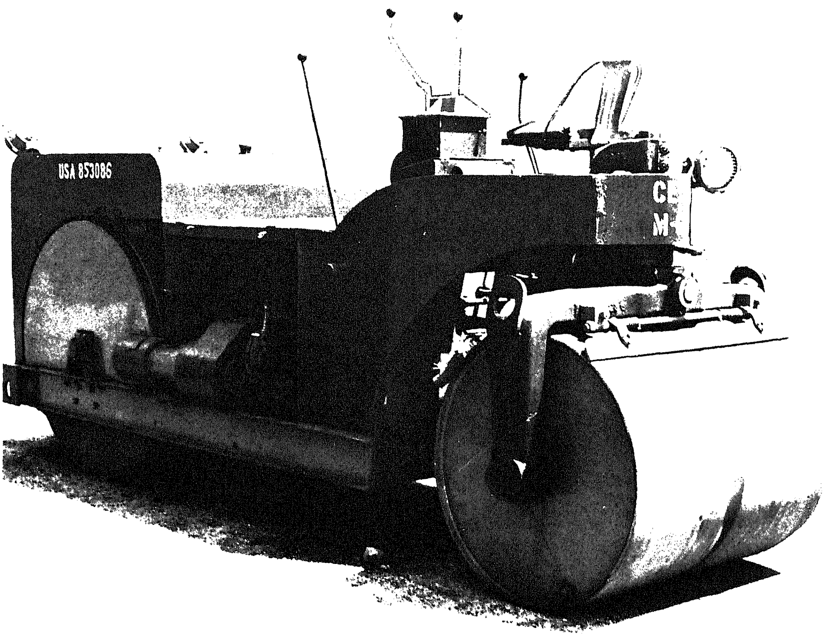


Figure 2–12. Two-axle tandem roller (5–8 ton).

allel, or at right angles to the direction of travel. The drive pinion to the rear rollers is located at one side. The two-axle roller (fig. 2–12) may be used to roll lengthways, across, or diagonally, but the three-axle roller (fig. 2–13) should only be used to roll lengthways to the roadway or runway. The three-axle tandem differs from all other types of road rollers and operates under a different principle. This roller has three large diameter rolls, all rigidly fixed on the same plane, and employs the principle of automatic transfer of weight. This means that when one roll is on a high spot in the material being rolled, it automatically "borrows" extra weight from one or both of the other two rolls. Figure 2–14 shows the approximate distribution of weight (with the roller fully water ballasted). When either the drive roll or the end guide roll is on a high spot, the center guide roll loses contact with the road surface, and its weight is transferred to the other two rolls. When the center guide roll is on a high spot, it receives extra weight from the end guide and drive rolls as shown. Therefore, instead of rolling over the high spot, the three-axle tandem levels it during the initial rolling, making it possible under most conditions to eliminate corrective rolling. This increases both the accuracy and the output of the machine. The three-axle tandem is especially advantageous on airport runways and large highway projects. Due to this "walking beam" action of the 9–14-ton roller, extra compaction effort can be applied to high spots in surfaced areas without readjusting the weight of the roller. These rollers, though primarily designed for compacting surfacing materials, are capable

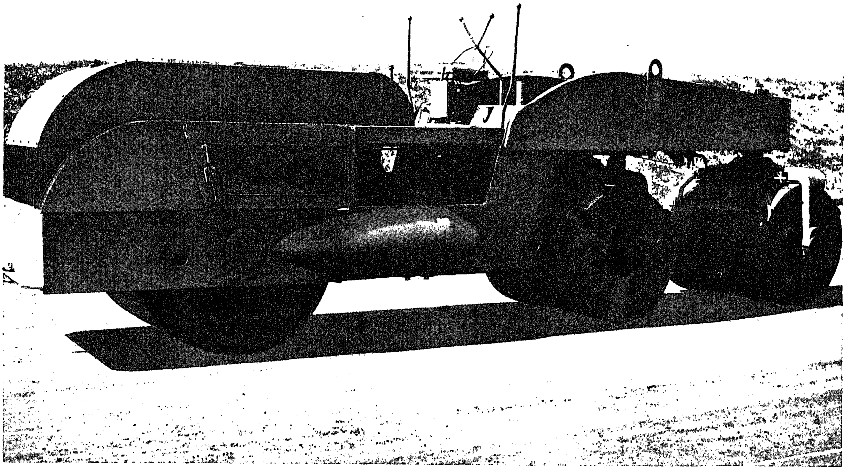


Figure 2–13. Three-axle tandem roller (9–14 ton).

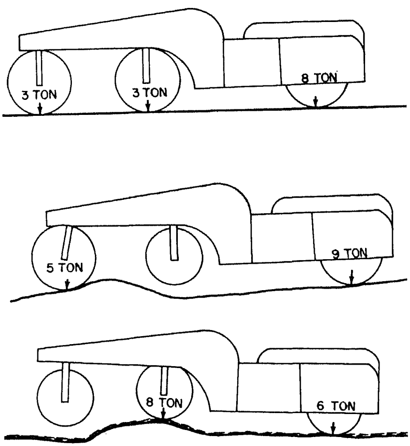


Figure 2–14. Weight distribution of three-axle tendem roller.

of compacting to a depth of 12 inches in friable, fine grained soils. They should not be used to compact coarse abrasive materials which will mar the face of the rolls, thereby making it less efficient for finish rolling of asphaltic materials.

2–11. Production Techniques for Tandem Rollers

a. On soft, pliable materials, the roller should be run at slower speeds so that material will not be excessively shoved or displaced. The roller should not be accelerated on a paving job.

b. When rolling hot and tacky material, the sprinkler system should be in perfect working condition.

c. Do not make sharp, fast turns. The roller must be steered slowly so the material will not be marked or shoved out of place.

d. Reverse the roller slowly and smoothly. One of the easiest ways of damaging pavement during construction is to reverse the roller too fast.

e. Do not allow the roller to stand on a cooling or setting road surface, as the weight ex-

erted by the rolls will leave depressions in the surface.

f. The project engineer or his representative will prescribe the amount or method of rolling necessary to obtain the desired results. Normally this is determined after rolling a test strip.

g. Production of these rollers is determined by the following formula:

Square yards per hour =

$$\frac{60 \text{ min/hr} \times \text{speed (in. ft/min)} \times \text{width (ft.)} \times \text{efficiency}}{\text{number of passes} \times 9}$$

Square meters per hour =

$$\frac{60 \text{ min/hr} \times \text{speed (mtr/min)} \times \text{width (mtr)} \times \text{efficiency}}{\text{number of passes}}$$

2–12. Steel Wheel Roller, Three-Wheel, 10-Ton

a. Characteristics. The standard three-wheel roller (fig. 2–15) has a pair of large drive rolls in the rear and a smaller but wider two piece steering toll in the front. One drive roll is fixed to the rear axle while the other runs free to insure easy turning of the roller, giving full differential action. However, when stiff axle operation is desired, a differential lock controlled by a lever in the cab locks the free roll to the axle and provides direct drive to both rear rolls. These rollers are self-propelled by gasoline or diesel engines and speeds range from 1.4 miles per hour in low (working gear) to 5 miles per hour travel speed. Some manufacturers make no provisions for ballasting these rollers to provide a range of compaction effort. This type is commonly employed by engineer units. The three-wheel rollers can be used in earthwork compaction because of the large diameter and great pressure exerted by the rear wheels. The bearing pressure exerted by steel wheel rollers is measured in pounds per linear inch or kilograms per centimeter. The passage of the guide roll often compacts the soil sufficiently to build up a bearing capacity for the drive rolls; but to insure maximum compaction effort, a thorough coverage by the drive rolls is necessary.

b. Bearing Pressure and Contact Area. Three-wheel rollers adjust their contact pressure to the bearing capacity of the soil by simply sinking to that depth which provides adequate area to equalize the unit pressure. On hard surfaces the rolls are tangent to the surface, so bearing pressure is measured in pounds per linear inch. This bearing pressure varies as the rolls sink in, but on a hard surface it is 335 to 400 pounds per linear inch for the rear rolls and 125 to 150 pounds per linear inch for the front roll. This roller is capable of compacting lifts of 10 to 12 inches, especially on friable, fine-grained soils. It is best used for compacting base courses of crushed rock.

2–13. Production Techniques for Three-Wheel, 10-Ton Roller

a. When rolling crowned areas start at the low side and work to the high side. Starting on the high side has a tendency to push the material to the low side.

b. Do not make sudden stops; this tends to push the material ahead of the rolls, damaging the area.

Figure 2–15. Three-wheel 10-ton roller.

c. Make slow gradual turns to prevent the edge of the rolls from digging and spinning on the compacted area.

d. During operation do not slip the master clutch as slipping causes excessive heat and wear.

e. Do not start the roller with the master clutch.

2–14. Nine-Wheel Self-Propelled Pneumatic Tired Roller

The nine-wheel self-propelled pneumatic tired roller (fig. 2–16) allows excellent maneuverability in tight quarters since it eliminates the necessity of a towing vehicle with the accompanying wide turning radius. Further, this roller can work in both forward and reverse gear thereby eliminating turns at each end of the lift section. This roller has a built-in capability to vary the tire pressure, and resulting contact pressure on the soil, while in motion. The roller has an empty weight of 8,000 pounds, making it air transportable in a CH–47A helicopter after collapsing the seat and steering column. Once on the job it can be ballasted to 20,000 pounds. It has a top speed of 25 miles per hour empty and 20 miles per hour ballasted. The nine-wheel roller is excellent for the compaction of granular soils and should be used for compaction of shoulders, subbases, and stabilized bases. In loose or weak soils the operator should start compaction with a low tire pressure to prevent rutting and shoving of the soil. As the soil begins to compact and its bearing strength increases, the operator should raise the tire pressure to increase the compactive effort on the soil. With a very high tire pressure, this roller can be used on bituminous surfaces.

Figure 2–16. Nine-wheel self-propelled pneumatic tired roller.

Secton III. VIBRATORY COMPACTION EQUIPMENT

2–15. Introduction

a. Vibratory compactors make use of the fact that loose soil materials can be consolidated by vibrations. It had been a matter of common ex-

perience that vibration due to machinery, traffic, and pile driving increased the density of sand under and around the source of vibration. After World War I, compactors were designed to make use of this principle in soil compaction for construction purposes. The earlier designs used a rectangular steel plate for the vibration contact area. More recently manufactured vibratory compactors also use pneumatic tires and banks of steel wheels for contact surfaces to transmit the vibration. Many variables are involved in vibratory compaction, but if properly applied, it can be one of the most economical means of obtaining high densities of compaction. Use of this method has rapidly increased in popularity in recent years.

b. Measurement. Vibration has two measurements—*amplitude,* which is the measurement of the movement, or throw, and *frequency,* which is the rate of the movement, or the number of oscillations per second or minute. The amplitude controls the effective area, or depth to which the vibration is transmitted into the soil, while the frequency determines the number of blows or oscillations that are transmitted in a period of time over the effective area.

c. Capabilities and Limitations. The advantages of a roller containing a vibrating element are its maneuverability and the small size of the tractor or other powerplant required to move it about. Its one disadvantage, which in many cases is not serious, is the width of the area of contact in the direction of rolling. The effective depth for compacting dry sand may be two to three times the width of the plate, but for cohesive soils it may be limited by a depth equal to the width of the plate. As an example, an experimental vibrator having a 3- × 5-foot baseplate produced densities of between 90 and 95 percent of the modified AASHO maximum density in a matter of 10 seconds to a depth of 6 feet in a dry sand. Considering the depth of compaction, a plate type compactor should be able to consolidate a greater yardage per unit of time than a roller. This advantage is only of significane when a depth of compaction to several feet is desired. There would be little advantage in using such equipment on a thin layer of the thickness normally used with a sheepsfoot roller or the heavy rubber-tired compaction equipment, unless the weight of the equipment is a factor. At the present time, large plate compactors are less maneuverable than rollers.

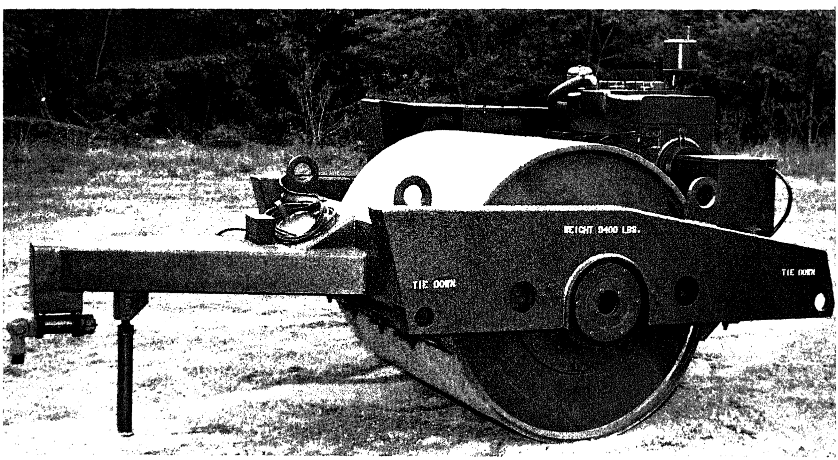


Figure 2–17. VP9D vibratory roller.

2–16. Steel Wheel Vibratory Compactor, VP9D

Although steel wheel vibratory rollers are manufactured as one, two, and three axle units, the standard model in the U.S. Army is the VP9D single axle smooth drum towed roller (fig. 2–17). Vibration is produced by an offset eccentric shaft powered by an air-cooled diesel engine and can be adjusted in the 1,200 to 1,500 vibrations per minute (vpm) range. This roller has a comparatively light static weight of 9,400 pounds but the 18,000 pounds dynamic force produced by vibration give it a total compactive effort of 27,300 pounds. A remote control system gives the operator of the towing tractor control over the starter throttle and stop lever of the roller engine. The contact area or maximum dynamic force is almost linear and each soil particle is under the roller for only one vertical impulse. Before and after this single vertical impulse the vibration direction is angular and changes with each impulse. The speed at which the roller is towed affects the number of blows on a given area. Slower speeds deliver more blows per linear foot and consequently reduce the total number of passes required. At a towing speed of 2 miles per hour and vibration frequency of 1,200 to 1,300 vibrations per minute this roller delivers an average of 7 impact blows per linear foot. The maximum recommended loose lift depth of be compacted by this roller is 12 inches. Before starting a job a test strip of the same material used on the job should be rolled to determine the optimum conditions, that is, vibration frequency, towing speed, lift depth, and moisture content.

2–17. Jay Tamper

This unit is a small tamper, self-contained and self-propelled, that has interchangeable shoes of 24, 30, and 36 inches. No auxiliary equipment or supply lines hamper its operation. It delivers 2,300 3,000-pound blows per minute. The unit weighs approximately 435 pounds and is powered by an air cooled 4.6-horsepower gasoline engine. In appearance it is similar to a power lawnmower. It is extremely useful for performing compaction in confined areas and can work at speeds of 15 to 45 feet per minute. Other manufacturers build this type compactor using electric power or air power to transmit an interrupted energy to the contact plates. The plates may be mounted in gangs held in a lift frame on a tractor which also carries the unit supplying the power to the plates.

2–18. Effect on Soils

The best material for base and subbase construction is the nonplastic and cohesionless sands and gravel. While these materials can be readily compacted to high densities using static weight compactors, the vibratory type compactors prove more effective. Most work with vibratory compaction equipment has been on sand or sandy loams, although there is an increasing tendency toward its use on cohesive soils, sometimes indiscriminately. The value of vibration is clearly evident and understandable for noncohesive materials, but is far less understood for cohesive soils. Cohesive soil particles are bound by many forces not yet clearly understood. Electrical charges, intermolecular attraction, surface tension, and other phenomena have been offered as explanations. But the end result is that such soils do not permit the particles to flow over and around each other freely. The forces bonding the particles must be broken by force. Moisture has an important effect on the compaction ability of soils. Soils with moisture less than the optimum do not compact as completely as those with optimum moisture, and those above the optimum approach a plastic stage and begin to act as liquids, distributing an applied force equally in all directions and, therefore, not moving particles into the voids. When a vibrator is operated through a range of frequencies (vibrations per minute) with a constant dynamic force, there will be one frequency

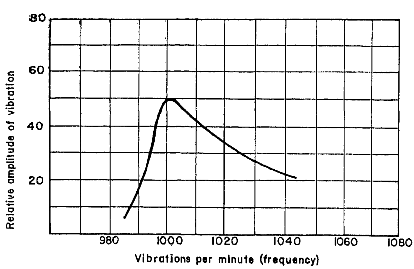


Figure 2–18. Typical resonance curve of soil-mass vibrator.

at which the soil and vibrator will vibrate much more strongly than at any other frequency. This condition is known as "resonance." The typical soil resonance curve (fig. 2–18) is steep, and resonant effects are appreciable over only a very small range. Thus, any attempt to gain the amplification effects of resonance requires extreme accuracy in measurement and control, and is rather impractical for present day equipment. Fortunately, if the soil is forced to vibrate at some frequency other than the resonant one, it will still compact because the particles are still forced to shake into the voids. Obviously, the higher the dynamic force the more particles will move and the more effective is compaction.

Section IV. ANCILLARY EQUIPMENT

2–19. Water Distributor, Truck Mounted

a. Description. The 1,000-gallon capacity water distributor mounted on a 5-ton truck chassis (fig. 2–19) is equipped with a self-priming pump, a rear mounted 12-foot folding spraybar assembly, and a fifth-wheel type tachometer. The integrally mounted pump is designed to supply water under various selected pressures to the spraybar or discharge hose. The tachometer supplied with this unit is mounted under the truck cab. A direct reading odometer type head fastened to the front side of the instrument panel is used to find a correct reading in feet per minute of the rate of truck travel. There are various makes and models of this water distributor found in the Army supply system.

b. Utilization. The water distributor is designed and built for use on all types of soil stabilization or surface construction where it is desirable to apply water with a positive and accurate distribution over a wide area. The unit also can be used as an all-purpose power pumping unit for the unloading and transferring of water or various other liquids having a viscosity or weight similar to that of water from one outside source to another. The unit can be used as a water transport vehicle for auxiliary or emergency firefighting. For use in firefighting, a multiple discharge manifold may be added to the discharge piping and several lines of hose can be used at one time. This unit is capable of self-loading using the power pumping unit and a 3-inch suction hose. The maximum lift to be expected with this unit with the line free of all leaks is approximately 20 feet. Water can be applied under various pressures utilizing the pumping unit or through a gravity feet system to the spraybars. The length of the spraybar may be varied in 1-foot increments from 4 to 24 feet. These features coupled with the ability to control the forward speed in feet per minute provide a capability of controlled application.

c. Production Estimation. Water distributors are most commonly used to apply water in controlled quantities on the subgrade area. They must work ahead of the compaction equipment so that the rolling operation is not slowed down and still insure that the proper amount of water is applied. The controlled application of specific quantities of water over a given area is dependent upon three major variables: pumping pressure, truck speed, and spraybar length. Knowing the amount of water required per

Table 2–2. Water Application Chart

Application (gallons per sq yd)	Water pressure (pounds per sq in.)	Truck speed (ft per min)
0.10	5	879
0.10	15	1,284
0.10	22	1,528
0.20	5	435
0.20	15	642
0.20	22	764
0.30	5	290
0.30	15	428
0.30	22	508
0.40	5	218
0.40	15	321
0.40	22	382
0.50	15	257
0.50	22	305
0.60	15	214
0.60	22	254
0.70	22	218
0.80	22	191
0.90	22	169
1.00	22	152

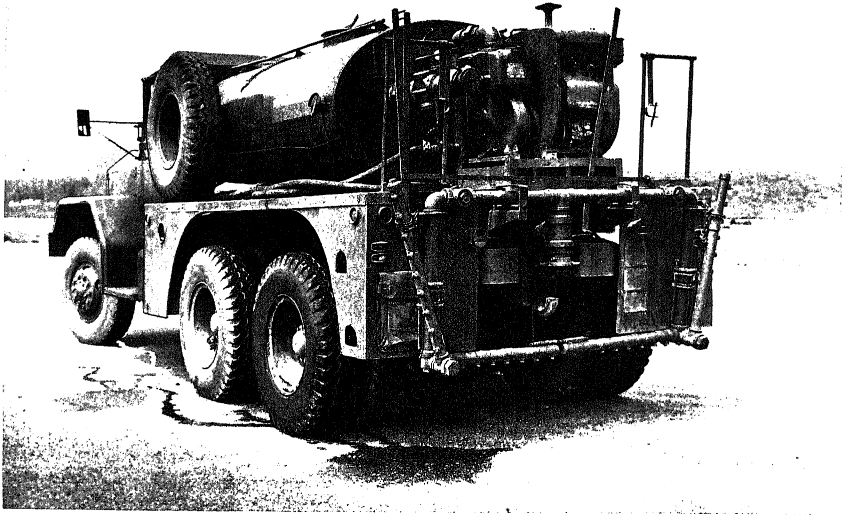


Figure 2–19. Water distributor.

square yard of loose lift and establishing a desired spraybar length, the other two variables, truck speed and pump pressure, can be computed from table 2–2. After the pumping pressure has been determined, consideration must be given to a drop of pressure due to line loss. The pressures depicted in the chart are pressures required at the nozzle of the spraybar. When a 12-foot spraybar is used and a 20-pound pressure is required at the nozzle, the pump pressure gage should read 24 psi, allowing 4 pounds difference to overcome line loss. The nozzles are of the fan type and are inserted in the spraybar at an angle of approximately 7° off the horizontal line of the spraybar. For a uniform spray, care must be taken to insure these nozzles are in proper alinement. The computation of cycle time of the water distributor, area covered by one distributor, and area required to be covered per hour will determine how many distributors are necessary to keep abreast of earthmoving operations and ahead of compaction equipment.

Step 1: In the formulas for determining the number of water distributors required to support compaction operations when adding water on a fill site area, first determine the area covered by one distributor.

$$\text{Area covered (sq yd)} = \frac{\text{distributor capacity (gal)}}{\text{gal required/sq yd}}$$

Step 2: Determine the length of this area:

$$\text{Length of area covered (ft)} = \frac{\text{area covered (sq yd)} \times 3}{\text{spraybar length (yd)}}$$

Step 3: Determine the time required for spraying:

$$\text{Distributing time (min)} = \frac{\text{length of area covered (ft)}}{\text{speed of distributor (ft/min)}}$$

Step 4: Determine the total distribution cycle time:

Cycle time = travel time + loading time + distributing time

Step 5: Determine the hourly output of one distributor:

$$\text{Hourly output} = \frac{60\ (\text{min/hr}) \times \text{distributor capacity}}{\text{cycle time (min)}}$$

Step 6: Determine the number of distributors required:

$$\text{Number distributors required per hour} = \frac{\text{gallons required per hour}}{\text{hourly output of one distributor}}$$

2–20. Rotary Tiller Mixer

a. Familiarization. The rotary tiller, either the self-propelled type (fig. 2–20) or semitrailer unit, consists of a rotor assembly and a mixing chamber. The rotor assembly consists of a shaft, tine holding plates, and tines mounted across the direction of travel under a mixing chamber. Recent models incorporate a pump mounted on the front of the unit and a spraybar in the mixing chamber. A rolled plate at the trailing edge of the mixing chamber acts as a strike-off to provide a smooth surface. The tine holding plates are driven by a shaft through individual friction clutches designed to slip momentarily under shock loads. A variety of interchangeable tines can be obtained for different working conditions.

b. Characteristics. The rotary tiller is used primarily in mixing and stabilizing road bases and surfaces and earth fill embankments. It controls the material, insuring that coarse and fines are mixed, blended, and placed so that aggregate segregation is completely corrected. All sizes of material which it is working, from dust to the largest gravel, are uniformly distributed; the aggregate is keyed and interlocked; and the voids are filled with fines.

c. Capabilities and Limitations. The self-propelled rotary tiller is capable of traveling from jobsite to jobsite at speeds up to 15 miles per hour under ideal road conditions. The hood board of the mixing chamber must be closed tightly for all mixing operations. As shown in figure 2–21, there is need for maintaining a closed mixing chamber to promote spillover and proper blending and mixing. This spillover must be controlled. If allowed to pile up excessively, it will cause a drawbar overload and also side spill, causing a disfigurement of the mixed material. Utilizing the forward mounted pump and the spraybar, liquids may be added to the soil in controlled quantities. This is especially useful for soils stabilization using cements, bitumens, and calcium chloride solutions. The tiller can also be used to construct bituminous surfaced roads. The forward speed

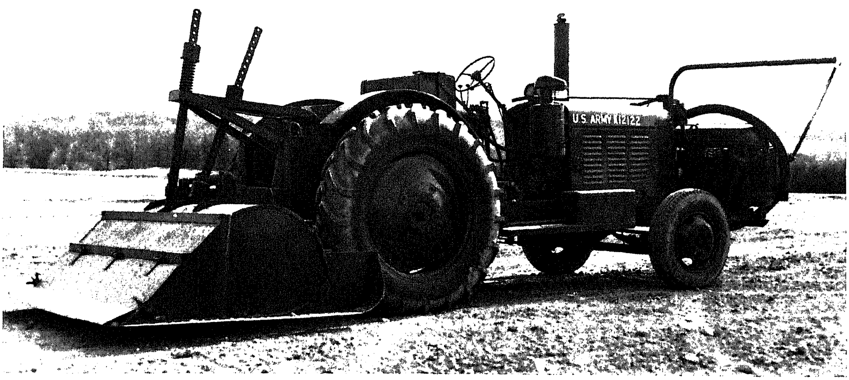


Figure 2–20. Rotary tiller.

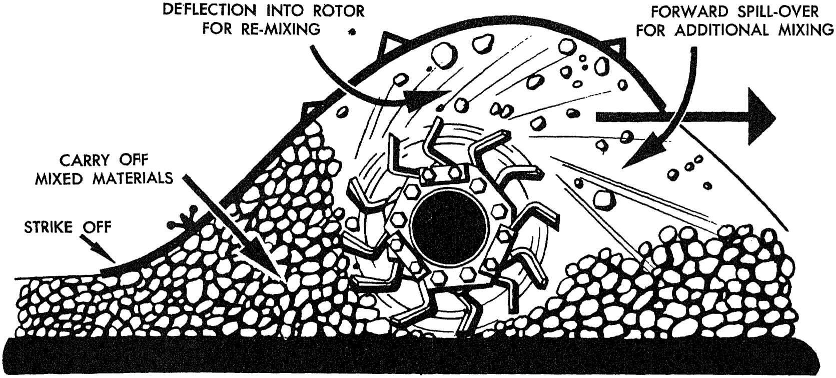


Figure 2–21. Mixing action in rotary tiller.

of the mixer and the pumping pressure can be very closely controlled, thus permitting close control when adding an admixture to the material. The tines are so constructed that they can penetrate to a depth of 10 inches below the surface under ideal conditions (newer models can penetrate up to 24 in.). Large rocks beneath the surface will limit the depth of penetration. Where it is necessary to remove excess moisture from the soil, exposure to air is the main drying method. Drying is done with the tailboard raised to permit the material to be cast through the air. Where it is necessary to remove excess bitumen from the material, the heat of the sun is the means used; therefore, the material is remixed with the tailboard in the closed position. Aerating this mix with an open hood is often a mistake because of excessive cooling and consequent reduction in the volatilization of the solvents.

d. Application Rate Determination. The rotary tiller equipped with a pump is used in the same manner as the water distributor; that is, a combination of traveling speed, pumping pressure, and spraybar length must be considered in controlling the application of water. The advantage of a rotary tiller is that water is applied to the soil while it is being mixed by the tines in an enclosure beneath the hood of the tiller. Gravel larger than 4 inches cannot be mixed with this tiller. Different models have different pumping rates and gear ratios, so the specification sheets or appropriate operator's manual should be consulted to determine application rates at various speeds.

Section V. SELECTION OF COMPACTORS AND EMPLOYMENT

2–21. Soil Considerations

When starting compaction on a project, even though operators and inspectors are experienced, it is worthwhile to conduct tests on trial lifts to determine the best rolling procedure. Assuming there is no choice of equipment, then test rolling is limited to determining the best lift thickness which can be compacted, the number or passes required for the major soil types encountered, and the need for increasing or decreasing compactive effort. These rolling tests should include a minimum of variables, and the soil should be at optimum moisture content. Usually three lifts are sufficient to show the minimum rolling necessary to produce the required density. The length of the

rolled area, while otherwise not significant, may have considerable influence on densities in hot summer months when the moisture evaporation rate is high. Quick handling of soils on the grade often means the difference between obtaining adequate densities with few passes and the addition of, and mixing in, of water. The proper balance between earthmoving and compaction equipment is necessary if compaction is to be adequate and economical. The two values should balance as nearly as possible, with an ample reserve roller capability available if conditions change from a soil that requires minimum rolling to a soil requiring greater effort.

2–22. Factors Governing Selection of Compactors

There are too many variables involved to make a definite statement that a certain type roller should be used for all phases of compaction. But by knowing the characteristics of different types of rollers, their capabilities and limitations, an intelligent selection can be made and rollers that obviously will not accomplish the desired compaction can be eliminated. Possibly the best way to discuss this subject is to approach it from the different stages of construction and what compaction equipment is used in each stage.

a. Embankment Construction. The term "embankment" as used here refers to that part of the raised structure below the depth of the subgrade material influenced by traffic loads and effects of climate. The purpose of densification is to prevent detrimental settlement and to aid in providing stable slopes. The materials normally used in this area are soil, soil-aggregate, or rock. Desired densities range from 90 to 100 percent AASHO, with the 100 percent AASHO required in areas subject to inundation. Sheepsfoot rollers which produce high unit pressures and other types of rollers which produce heavy wheel loads and high unit pressures permit securing desired densities at low moisture content. Pneumatic tired rollers generally will handle thicker lifts than a sheepsfoot, so that if rocks or cobbles are present they usually can be incorporated into the fill without undergoing the loss of time for their removal. Fills or portions of fills subject to inundation or scour should be compacted at near optimum moisture content to lower the permeability and offer a greater resistance to softening of the fill material.

b. Subgrade Compaction. The term subgrade material is intended to include soil to the depth which may affect structural design or the depth to which climate affects the soil, whichever is the greater. This area may be in depths up to 10 feet for pavement carrying heavy loads. Heavy pneumatic tired rollers are preferred in this area due to their production capabilities and depth of compaction effort. Sheepsfoot rollers may be used to break up soft oversize rock in this area and can also be used for compaction throughout the subgrade area. Another roller, steel wheel or rubber-tired, will be required to dress up the surface of the final lift when using the sheepsfoot roller. This other roller can also be used to seal off the surface when rain is anticipated during construction. If the material in the subgrade area is sand, a vibratory type compactor would be the most efficient item to use. In the absence of a vibratory type compactor, a crawler-tractor with loosened tracks can be used to compact the sand; or a rubber-tired roller having low tire pressure may be used, but in this instance, the material must be compacted in shallow lifts, no greater than 2 to 4 inches in depth.

c. Base Course Compaction. The base course provides the strength of pavements. When subgrade strength is low, the stresses created by surface loads must be reduced to a low value, and a substantial thickness of base is needed. Where the subgrade strength is higher, a lesser thickness will provide adequate distribution. Since the stresses in the base course are always higher than in the subgrade, the base course must have a high strength. To meet this requirement a mixture of uniformly graded granular materials generally is needed, with a full range of particles from coarse to fines, and a top size of 1.5 to 2 inches. The material should have a Los Angeles abrasion loss of less than 50 percent, liquid limit less than 25 percent, and the plasticity index should be less than 6. Sheepsfoot rollers *are not used* in this area. Best results are obtained from rubber-tired rollers which compact, knead, and confine these granular particles. Steel wheel rollers can be used but they tend to displace the material laterally and are slow in operation. Steel wheel

rollers are efficiently used to dress off the wheel ruts of the pneumatic roller on the finished surface of the base course.

d. Controlling Loose Lift Depth. Material must be placed in depth controlled lifts, taking into consideration the maximum size of the aggregate and the shrinkage which will result from compaction. Normally, for each 1 unit of depth of compacted lift, 1.15 to 1.25 units of loose lift are required. However, the shrinkage factor should be checked, using a test strip.

2–23. Spreading

The placing and spreading of the material on the prepared subgrade, or on a completed layer, may begin at the point nearest the source or at the point farthest from the source. Material is then placed progressively away from or toward the source, respectively. The advantage of working from the point nearest the source is that the hauling vehicles can be routed over the spread material, which assists in compacting the base and avoids cutting up the subgrade. Advantages of working from the point farthest from the source are that hauling equipment will further compact the subgrade, reveal any weak spots in the subgrade so they can be promptly corrected, and interfere less with the movement of spreading and compacting equipment. When hauling vehicles are not desired on the subgrade and placing begins at the point farthest from the source, hauling vehicles should be routed over adjacent finished working strips and the material spread transversely at the point of deposit.

2–24. Compaction in Cut Areas

When suitable subgrade material is in place in cut areas, and the material is of a noncohesive nature, a vibratory compactor may compact it to a depth equal to two times the width of the contact plate, if a plate type vibrator is used. If the material is of a cohesive type, the 50-ton pneumatic tired roller normally will compact it to a depth of 18 inches in a very lean sand silt clay mixture but as the clay content increases the depth will decrease to 6–8 inches. In either case, test areas should be established to insure that compaction is accomplished to the desired depth. It may also be necessary to root the area and apply water to facilitate compaction. As a last record, in case the other methods do not obtain desired densities, it may be necessary to remove material, compact the underlying surface, replace the material in lifts, and compact each replaced lift.

2–25. Compaction of Clay Cores in Earth Dams

In a dam core, the compacted earth acts as an impenetrable barrier when seepage from the reservoir moves through the embankment. Engineers generally plan compaction in a dam so that percolation through the impervious barrier never reaches a danger point, with seepage through the pervious zones always under control. This paragraph is concerned only with the clay core compaction. Clay material is delivered to the site in various sizes and degrees of moisture content. To provide an impervious core, it is necessary to break the clods of clay into fine particles before compacting. This will minimize the possibility of forming voids. High pressure sheepsfoot rollers are used for initial fracturing of these clods and final pulverization is done with either a disk harrow or rotary tiller. Water is added until the moisture content is slightly above optimum and then the material is compacted using a sheepsfoot or heavy pneumatic tired roller. When using a rubber-tired roller, the tires will seal off the top of the lift, thereby preventing a bond between lifts. This can be partially corrected by lightly harrowing the finished compacted lift before the next lift is spread. The action of a sheepsfoot roller will provide a partial bond between lifts but enough passes must be made using the sheepsfoot roller to insure the lift is thoroughly compacted. Tests have revealed that material compacted by a sheepsfoot roller did not appear to compact uniformly, as hard and soft spots were noticeable throughout the compacted lane.

2–26. Organization of Compaction Operation

a. General Information. When earth is placed in a fill, it usually is necessary to spread, wet, shape, and compact it in accordance with well established engineering practices. The supervisor should select balanced equipment so that all operations may be synchronized as near as possible. Each project should have enough equipment to keep it in balance with

the overall operations. An analysis of the project will indicate the number of units of each type of equipment needed. For example, if the volume of earth placed requires 10,000 gallons of water per hour, enough water trucks should be provided to furnish this quantity of water. The job planner should start with the rate of delivery of earth to the fill; then from this information, determine the number of units of each type required to keep the job going smoothly. The amount of material per hour that one piece of equipment can compact can be estimated with the following formulas:

$$(1)\quad C = \frac{60\ (\text{min/hr}) \times S \times W \times D \times E}{N \times 27\ (\text{cu ft/yd})}$$

or:

$$(2)\quad C = \frac{60 \times S \times W \times D \times E}{N}$$

Where: C = Compaction in (1) cu yd/hr or (2) cu mtr/hr
S = Speed of compactor in (1) ft/min or (2) mtrs/min
W = Effective width of roller/compactor in (1) feet or (2) meters
D = Depth of lift in (1) feet or (2) meters
E = Efficiency factor of the compactor
N = Number of passes

b. Sample Problem. A project requires the placing of 1,000,000 cubic yards of earth for a dam. The job conditions are as follows:

Class of earth: sandy clay, 2,400 lb/cu yd *bank* measure, swell is 25 percent, compaction is 85 percent

Initial moisture content: 7 percent by weight

Required moisture content: 12 percent by weight

Maximum lift thickness: 6 inches compacted

Number of passes required (sheepsfoot roller): 12

Average distance to water: 1 mile

Earth hauling capability: 600 cu yd (compacted) per hour.

(1) *Spreading.*

Area covered per hour
$= 2 \times 600$ cu yd $\times$ 27 cu ft/yd
$= 32{,}400$ sq ft

Using a 100 hp grader with 12-foot blade; average speed including turns, stops, etc = 2 mph; effective width of blade = 9 feet; estimated number of passes per layer = 4.

Area covered per hour (one pass) =

$$\frac{2\ \text{mph} \times 5280\ \text{ft/mi} \times 9\ \text{ft/pass} \times 50\ \text{min}}{60\ \text{min/hr}}$$

$= 79{,}300$ sq ft

Area covered per hour, 4 passes =

$$\frac{79{,}300}{4} = 19{,}825\ \text{sq ft}$$

Number of graders required =

$$\frac{32{,}400}{19{,}825} = 1.6 \text{ or } 2 \text{ graders}$$

(2) *Wetting the material.*

Weight of earth placed per hour =

$$\frac{600\ \text{cu yd} \times 2{,}400\ \text{lb/yd}}{.85\ (\%\ \text{compaction})}$$

$= 1{,}694{,}000$ lb

Water to be added (by weight)
$= 12 - 7 = 5$ percent

Quantity of water required =

$$\frac{1{,}694{,}000\ \text{lb} \times 0.05\ (\text{percent})}{8.33\ \text{lb/gal}}$$

$= 10{,}170$ gallons

Use water trucks with 1,000-gal capacity

Loading pump will deliver 250 gal/min

The round trip time per truck will be—

$$\text{Loading time} = \frac{1{,}000\ \text{gal}}{250\ \text{gpm}} = 4.00\ \text{min}$$

$$\text{Hauling time} = \frac{1\ \text{mi} \times 60\ \text{min/hr}}{15\ \text{mph}}$$

$= 4.00$ min

$$\text{Sprinking time} = \frac{1{,}000\ \text{gal}}{150\ \text{gpm}}$$

$= 6.67$ min

$$\text{Return time} = \frac{1\ \text{mi} \times 60\ \text{min/hr}}{20\ \text{mph}}$$

$= 3.00$ min

Fixed time = 3.33 min

Total time = $4.00 + 4.00 + 6.67 + 3.00 + 3.33 = 21.00$ min

Trips per 50 min hr $= \frac{50}{21} = 2.38$

Quantity hauled per truck per hour $= 2.38 \times 1{,}000 = 2{,}380$ gal.

Number of trucks required $= \frac{\text{gallons required}}{\text{gallons/truck/hour}} =$

$\frac{10{,}170}{2{,}380} = 4.27$ or 5 trucks

(3) *Compacting the fill.*
Weight of 3-drum roller $= 21{,}570$ lb
Width of roller $= 12$ feet

Power required
$= 600$ DBPP per ton of weight
$= 600 \text{ DBPP} \times 11 \text{ ton} = 6{,}000$ DBPP required

Use a D–8 crawler tractor, 5th gear, 9,490 DBPP at 5.2 mph

Compaction

$$= \frac{60 \text{ min/hr} \times .83 \times (5.2 \text{ mph} \times 88) \times 12 \text{ ft} \times 0.5 \text{ ft}}{12 \times 27 \text{ cu ft/cu yd}}$$

$= 422$ cu yd/hr

Number of rollers required $= \frac{600}{422} = 1.4$ or 2 rollers

(4) Balanced team consists of—

Spreading	2 graders
Wetting	5 water distributors, 1,000-gal
Compacting	2 sheepsfoot rollers, 3-drum, with tractors

CHAPTER 3

DITCHING EQUIPMENT

3–1. Introduction

The two ditching machines most commonly used by the U.S. Army are the crawler mounted Model 44C and the pneumatic tired Model 750. Both models are designed for rapid excavation of general purpose ditching and trenching within their design capabilities. Both ditchers operate on the same principle: an endless chain arrangement of steel buckets digs the material, carries it upward, and deposits it on a conveyor belt which in turn transports the material to one side and dumps it. These ditching machines can traverse slopes of 11° or 20 percent while ditching. Both the Model 44C and the Model 750 ditchers can work in a variety of soil conditions ranging from relatively soft material up through tough or sticky clay, shale, and in some cases, semihard coral and thin pavements. As the material to be excavated becomes harder, of course, the production rate decreases. If attempts are made to excavate ditches in material that is too hard, damage to the unit will result. When rocky soil is encountered, and the rocks will fit within the bucket, the unit will still excavate. Many times, however, very large rocks will be in the trench line. If the bucket teeth cannot fracture them, then production ceases until they are removed. The ditchers can excavate curved trenches as long as the curve is not too acute. If an attempt is made to cut on a very acute curve, the bucket line of the unit can become jammed within the trench. When excavating curved trenches, wear is accelerated on the sides of the bucket line and continual practice of this nature will damage the machine.

3–2. Model 44C, Crawler Ditcher

The Model 44C is mounted on tracks with smooth pads, has a travel speed of from 1 to 8 feet per minute, and is capable of digging to a depth of 8 feet 3 inches. This unit normally digs a trench 18 inches in width, but with the addition of side cutters on the buckets and extensions for the followup scraper the digging width is increased to 24 inches. The discharge conveyor is a rubber belt with steel cleats, and has a maximum reach of 8 feet to either side from the centerline of the buckets. The depth gage consists of a side-mounted bracket with a chain and plumb bob attached which, when use in conjunction with a preestablished grade line on the surface, gives accurate depth control. The Model 44C ditcher must be transported from job site to job site by low-bed trailer or other means. The overall height of the ditcher can be reduced 5 feet (from 19 ft to 14 ft) by laying the boom out flat on the trailer. Even this reduced height of the ditcher when added to the trailer height creates a top-heavy load and makes overhead clearance a problem in route selection. The Model 44C is best suited for utility line construction and foundation excavation.

3–3. Model 750 Mobile Ditcher

The Model 750 mobile ditcher (fig. 3–1) is self-propelled and mounted on a four wheel, two wheel drive chassis similar to a truck chassis. It can reach a speed of 28 miles per hour on the highway. This unit has good cross-country mobility due to the high flotation provided by its large pneumatic tires. However, minimum speeds should be maintained when traversing rough country because there are no springs over the rear wheels and high speeds over rough ground will damage the unit. The Model 750 ditcher can dig to a depth of 6 feet 3 inches but is limited to a 24-inch width of excavation. This model is equipped with a dial type depth gage and accurate depth control is harder to achieve than with the Model 44C.

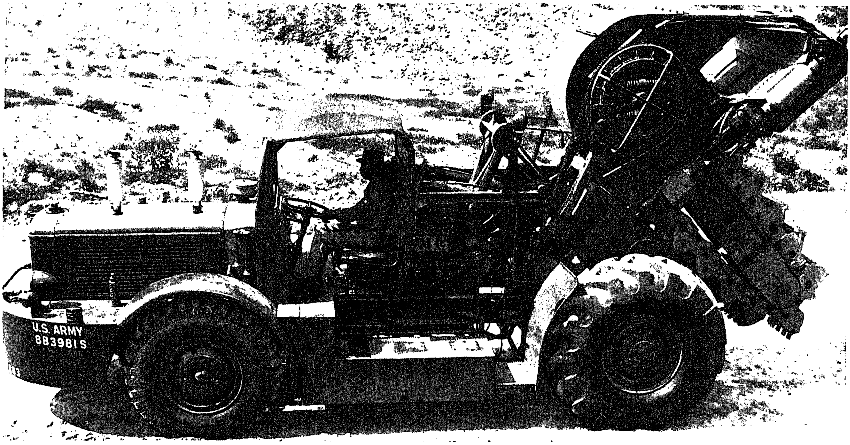


Figure 3–1. Model 750, mobile ditcher.

3–4. Site Preparation for Ditchers

Both the Model 750 and Model 44C can excavate ditches working parallel on a 15 percent slope, though this is their maximum. Working on this slope the ditch will be undercut. This undercutting will result in the trench wall caving, due to instability of the soil, or from water washing it in during inclement weather. If the trench is being excavated for a utility line, this situation would be hazardous for personnel working in the ditch. If the trench is being constructed for troop emplacements, then hand labor can be used to remove the overhang. For best operation on side slopes, a tractor dozer is used to bench off the slope ahead of the ditcher. This allows the ditcher to excavate a vertical walled ditch. In addition to this bench operation on side slopes, it is best to clear off brush ahead of the ditcher. Although it is capable of walking down small brush and tearing through it, better operation and control are maintained if the area has been cleared first.

3–5. Maintaining Grade and Alinement

a. Model 44C. A guide or grade line is established on the surface conforming with the desired depth and grade of the ditch. The grade line can consist of a string line or wire stretched on stakes, offset 49 inches from the center line of the ditch on the operator's side. The line is established off the ground, but not more than 24 inches in height. The operator is informed as to the initial depth of a cut and drives the bucket line into the ground. When he reaches the required depth the chain depth gage is adjusted to ride on top of the string line and he proceeds to dig. On level ground, the operator simply watches the chain on his depth indicator and keeps it just touching the grade line. Rough ground which tends to tilt the ditcher endways does not offer any serious complication in maintaining grade; however, it does require a closer watch of the depth indicator.

b. Model 750. With the Model 750 ditcher grade and depth can be maintained by two methods. First, the entire line of the ditch can be leveled off by a dozer or grader to conform with the desired grade and depth of the ditch. This would entail a great amount of site preparation on relatively rough terrain, but would be suitable for foundation excavation. Secondly, grade stakes can be offset from the center line of the ditch indicating depth of cut. These would have to be placed everywhere there is a change of surface elevation. The accuracy of this method would be dependent on the interval

between stakes, condition of terrain, and skill of the operator.

3–6. Below-Ground Obstructions

When digging in areas where pipe, conduits, or other objects have been installed, care must be exercised. The overload release sprocket on both models of ditchers is designed primarily to protect the machine and may fracture an underground installation before breaking power to the bucket line. Before digging locate any obstructions and plainly mark them on the grade line. Dig until the buckets are about 1 foot from the obstruction, then raise the bucket line while still digging. If the exact height of the obstruction is known, pass 1 foot over it still digging, then lower the bucket line back to the desired depth when 1 foot past it. If the exact height is not known the bucket line should be removed from the ground and the trench restarted past the obstruction. Care must be taken not to work closer than 1 foot to pipes or telephone cables, as a small rock may be forced against them by the bucket line and cause breakage.

3–7. Cutting in Excess of Rated Width

The maximum width of cut for both the model 44C and Model 750 is 24 inches. To attempt to exceed this cut by multiple passes will endanger the machine. The inside-to-inside track measurement of the Model 44C is 4 feet 10 inches and of the Model 750 is 5 feet 11 inches. To make a second pass to widen the ditch would move the tracks or tires in too close to the already excavated ditch. The ditch wall is very likely to collapse, damaging the machine and possibly injuring the operator. Furthermore, very little is gained by making multiple passes, for 50 percent of the material loosened on the second pass spills into the ditch already excavated.

3–8. Troop Emplacements

The Model 750 ditcher can be utilized for excavation of protective shelters or tactical troop emplacements. With the high mobility of this machine it can move rapidly from site to site, assisting a tactical unit to dig in. With its 24-inch width of cut it is ideal for the excavation of foxholes and weapons emplacements. It can excavate positions for automatic rifles, rocket launchers, machine-guns, recoiless rifles, and mortar emplacements. After excavation by the ditcher some hand labor is needed to arrange spoil piles and make further refinements of the position. Even for those trenches which are greater than 24 inches in width the initial cut will greatly increase the speed of excavation.

CHAPTER 4

SAFETY

4–1. Introduction

Time usually is the controlling factor in construction operations that require the use of engineer equipment, particularly in the theater of operations. The necessity for economy of time, coupled with the temporary nature of much of the work being done, sometimes results in the use of safety precautions which are substantially lower than those used in civilian practice. Such lowered safety standards should *not* be used as a general practice, but only in cases of extreme urgency. Relaxed general safety requirements may result in temporary increases in production but the *advantages so gained are often negated by damage to facilities or equipment, or by injury, and sometimes death to personnel.* Subsequent paragraphs give the basic safety rules which should be followed in all operations involving the use of earthmoving equipment. In circumstances where literal application of a requirement to a specific job has impractical aspects, the commanding officers of separate installations, activities, and units are authorized to approve an adaptation which meets the obvious intent of the requirement.

4–2. Indoctrination of Personnel

Safety should be taught to the operator during his operator training, but each job has its own safety hazards which are peculiar to the particular operation. These hazards must be identified, and a safety program which will reduce or eliminate them prepared. Once the program has been prepared it is the responsibility of supervisory personnel to see that it is carried out. Each person on the job should be given an initial indoctrination advising him of the hazards he may meet and the ways in which he can reduce or avoid them. He should receive continuing instructions during the progress of the job to make sure the objectives of the safety program are met. Personnel should be instructed to watch out for fellow workmen and warn them when they get into dangerous positions. Horseplay, wrestling, scuffling, practical jokes, or unnecessary conversation must be avoided during working hours.

4–3. Operation of Equipment

Before any mechanized equipment is put into use on the job, it should be inspected and tested by a qualified person and determined to be in safe operating condition. Continued periodic inspections should be made at such intervals as necessary to assure its safe operating condition and proper maintenance. Any machinery or equipment found to be in an unsafe operating condition should be tagged at the operator's position—"Out Of Service, Do Not Use," and its use prohibited until unsafe conditions have been corrected. Mechanized equipment must be operated only by qualified and authorized personnel. It will not be operated in a manner that will endanger persons or property, nor will the safe operating speeds or loads be exceeded. Equipment requiring an operator will not be permitted to run unattended. Mounting or dismounting equipment while in motion, or riding on equipment by unauthorized personnel, is prohibited. An operator should not be permitted to operate any machinery or equipment for more than 10 hours without a consecutive 8-hour interval of rest. All equipment not equipped to prevent overloading or excessive speed will have safe load capacities and/or operating speeds posted at the operator's position.

4–4. Guards and Safety Devices

Guards, safety appliances, and similar devices are placed on equipment for the protec-

tion of personnel, and must not be removed or made ineffective except for the purpose of making immediate repairs, lubrication, or adjustment, and then only after the power has been shut off. All guards and devices must be replaced immediately after completion of repairs and adjustments. When used in clearing operations, dozers, tractors, and similar equipment should be provided with substantial guards, shields, canopies, or grills to protect the operators from flying or falling objects, as appropriate to the nature of the clearing operations undertaken. When the provision of such protection is impractical, operational procedures must be established to minimize the danger of injury to personnel and damage to equipment. Equipment having a drop-type-skip pan must be provided with guards to prevent personnel from walking under the skip.

4–5. Repairs and Maintenance

All equipment must be shut down or positive means taken to prevent its operation while repairs, adjustments, or manual lubrications are being made. Repairs should be made at a location and under conditions which will provide a safe place for the repairman. Heavy machinery, equipment, or parts thereof which are suspended or held apart by use of slings, hoists, or jacks must also be substantially blocked or cribbed before men are permitted to work underneath or between them. Dozer and scraper blades should be lowered to rest on the ground or on suitable blocking when not in use.

4–6. Use of Signals

A uniform system of signals must be used on all operations of a similar nature. The signals in use should be posted at the operator's position, at signal control points, and at such other points as necessary to properly inform those concerned. Where manual (hand) signals are used, only one person will be designated to give the signals to the operator. This signalman must be located so as to be clearly visible to the operator at all times. Only persons who are dependable and fully qualified by experience with the operations being directed will be used as signalmen. A signalman will be provided whenever the point of operation is not in full and direct view of the machine or equipment operator. A warning device or services of a signalman will be provided wherever there is danger to persons from moving equipment. Highway operated equipment should be equipped with turn signals.

4–7. Night Operations

All mobile equipment will have adequate headlights and taillights when operating in hours of darkness. Construction roads and working areas will be adequately lighted while work is in progress at night. Lighting will be maintained until workmen have had an opportunity to leave the area. Personnel working in darkened areas and exposed to vehicular traffic, such as signalmen, spotters, inspectors, servicemen, and others whose presence is required for a prolonged time, will wear vests or apparel marked with a reflectorized material.

4–8. Transporting Equipment

Much of the earthmoving and other construction equipment is considerably larger in size, weight, and especially width, than other vehicles. Therefore, equipment of this type must be given special consideration whenever traveling, or being transported, from one jobsite to another. Generally, oversize equipment should be transported during daylight hours whenever possible. Equipment that is wider than standard vehicles, or protrudes past the ends or sides of the truck or trailer hauling it, should be equipped with warning flags and/or lights as necessary. In addition, such oversize loads should be preceded by a lead vehicle with a warning sign whenever possible, especially in congested or heavy traffic areas.

4–9. Operator Safety Rules

The lack of documented harzards and pertinent precautions are not to be construed as an indication of their nonexistence or unimportance. Where safety precautions are considered to be necessary but have not been provided, or where existing precautions are judged to be inadequate, the commanding officer will issue new or supplementary precautions deemed necessary for the protection of personnel and property. Listed below are some specific rules for earthmoving equipment.

a. Crawler Tractors and Dozers.

(1) Workmen should never ride on the drawbar of a tractor.

(2) Do not attempt to turn around on steep slopes, back up or down.
(3) When towing a heavy load downhill, keep the tractor in low gear.
(4) Always lower blades and tractor drawn attachments when machine is idle.
(5) Always disengage master clutch and put machine in neutral when starting engine.
(6) No more than two men should be on the machine while in operation.

b. Rubber-Tired Tractors.

(1) Never work or stand between the rear wheels and frame of the 830M and 290M tractors while the engine is running.
(2) Use hinge straps to pin the blade to the frame of the machine when traveling long distances with the 830M or 290M tractors.
(3) Use seat belts when machines are equipped with them.
(4) On 830M and 290M tractors, do not attempt to check radiator levels by climbing up on the blade. Climb the ladder and walk on hood of the machine.

c. Graders.

(1) Whenever a grader is operating slowly on a highway or roadway, a red flag or flashing light should be displayed on a staff which projects at least 6 feet above the left rear wheel.
(2) Personnel should never ride on the tandem, moldboard, or rear of the grader.
(3) Always engage the clutch gently, especially when going up a hill or pulling out of a ditch.
(4) Always reduce speed before making a turn or applying the brakes.
(5) Always keep the grader in low gear when going down steep slopes.
(6) When working on hillsides, take extra care to drive slowly and watch out for holes or ditches.
(7) Never use graders to pull stumps or other heavy loads.
(8) Keep moldboard angled well under machine when not in use.
(9) No more than two men should be on the machine while in operation.

d. Ditchers.

(1) Operators should never leave the operator's position while the machine is in operation or the engine is running.
(2) Personnel should never attempt to remove objects from the conveyor or buckets while the machine is running.
(3) Workmen should never stand on the ditching machine, or between the machine and high banks of soft material.

APPENDIX

REFERENCES

1. Field Manuals

FM 5–1 Engineer Troop Organizations and Operations.

FM 5–34 Engineer Field Data.

FM 5–36 Route Reconnaissance and Classification.

FM 5–142 Nondivisional Engineer Combat Units.

FM 5–162 Engineer Construction and Construction-Support Units.

FM 21–60 Visual Signals.

2. Technical Manuals

TM 5–330 Planning, Site Selection, and Design of Roads, Airfields, and Heliports in the Theater of Operations.

TM 5–332 Pits and Quarries.

TM 5–333 Construction Management.

TM 5–337 Paving and Surfacing Operations.

TM 5–343 Military Petroleum Pipeline Systems.

TM 5–360 Port Construction and Rehabilitation.

TM 5–530 Materials Testing.

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USA Engr RD Lab (3)
USATCFLW (30)
Cen (2)

NG: State AG (3).
USAR: Same as active Army except allowance is one copy to each unit.
For explanation of abbreviations used, see AR 320–50.

* U.S. Government Printing Office : 1967—O 275-226